The Aftermath of Hurricane María on Puerto Rican Small-Scale Fisheries

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Abstract

In September 2017, Hurricane María hit the Commonwealth of Puerto Rico threatening the economic and social viability of small-scale fisheries. This study describes the main results of a rapid socio-economic assessment of the storm's impacts one year after it made landfall.

María caused commercial landings to fall by 20% owing to the loss of productive assets, extended power outages, and the loss of customers. Most of the fishing activity recovered when electric service became widely available, particularly in the metropolitan area. The small-scale fisheries lost $17.8 million, excluding post-harvest impacts. Damaged fishing capital (vessel, engine, gear) and shoreside infrastructure accounted for 51% of the losses and forgone fishing revenue for the remaining 49%.

The east coast was the hardest hit accounting for 48% of the domestic landing losses. Traps, handlines, and commercial diving suffered the most losses. Fishers reported losing 70% of their traps and having to dive in deeper waters for queen conch. Other than switching landing and marketing sites, few fishers changed their fishing and fishing-related practices probably because these were tuned to local ecological conditions and occupational multiplicity strategies. The study also found that bonding and bridging social capital contributed to the recovery of fishers' livelihoods.

Keywords: Puerto Rico; small-scale fisheries; Hurricane María; socio-economic impacts; social capital

1. Introduction

On September 20, 2017, Hurricane María (hereafter María) made landfall near the southeast tip of the Commonwealth of Puerto Rico. This Category 4 hurricane was one of the worst natural disasters in the island's history causing an estimated 3,000 deaths and $43 billion in damages and losses (Santos-Burgoa et al. 2018; Junta de Planificación de Puerto Rico, 2018). María left much of the entire population of 3.3 million residents without electricity, running water, and communications for months. This study examines the major socio-economic consequences of María on Puerto Rican small-scale fishers one year after its landfall.[1]

Small-scale fisheries provide a unique setting to understand how vulnerable, resource dependent communities cope with extreme weather events because these events can affect their ability to secure resources for sustenance and income (Coulthard, 2008; van der Berg, 2010; Badjeck et al. 2013; García-Quijano and Poggie, 2020; Metcalfe et al, 2020). In addition to disrupting regular fishing operations, extreme weather events can also damage fishing capital (vessel, gear and equipment), shoreside infrastructure, and other productive assets, and also endanger the lives of those in close proximity to coastal areas (Pomeroy et al. 2006; Badjeck et al. 2010; Badjeck et al. 2013; Cinner et al. 2018). Depending on the degree of susceptibility and exposure of the fishing community, external assistance may be required to rebuild the community and have their members return to their livelihoods promptly (Westlund et al, 2007).

[1] Although the paper focuses on the aftermath of María, hurricane Irma and late season (post-María) swells may have confounded some of our survey results. Irma passed near San Juan two weeks prior to María, but missed the island. Nevertheless, it brought heavy rains and strong gusts that left 60,000 people without power. In addition, heavy swells in late 2017 and early 2018 caused additional damage to already debilitated coastal infrastructure, including fishing centers.

This study describes the main results of a rapid socio-economic assessment of María's impacts on Puerto Rican small-scale fishing communities one year after it made landfall. To contribute to policy, we assess the economic impact to the sector, examine factors that influenced recovery, and investigate the coping mechanisms employed.

2. Puerto Rican Small-Scale Fisheries

Puerto Rican commercial fisheries are small-scale in nature, but the sector serves as an important source of sustenance, income, employment, and cultural heritage to many coastal communities (Gutiérrez-Sánchez, 1982; Pérez, 2005; Griffith et al. 2007; Valdés-Pizzini, 2011; Agar et al. 2017). Fishers operate around the entire archipelago, which consists of the main island of Puerto Rico and several smaller islands and cays, including Vieques, Culebra, and the fishing banks near the islands of Mona and Desecheo (Figure 1). The archipelago has an overall area of 3,515 square miles and a coastline that extends for 311 miles (Cadilla, 1988).

In 2016, Puerto Rican fishers landed about 2.4 million pounds (mp) of finfish and shellfish worth $10.3 million in dockside revenues (NMFS, 2019). There are around 1,200-licensed fishers, but only about 1,000 of them (including crew) show up in fishery statistics (NMFS, 2019). Most fishing vessels are small and have moderate levels of mechanization (Matos-Caraballo and Agar, 2011). Fishers use a number of gears such as scuba and skin diving (including spearfishing), hook-and-line, traps, and nets to target spiny lobster, queen conch, reef-fish, and miscellaneous coastal pelagic species (Matos-Caraballo and Agar, 2011; Tonioli and Agar, 2011). A captain and a deckhand (known as *proel*) run most fishing operations, with the exception of dive operations, which have larger crews because of productivity and safety reasons (Agar and Shivlani, 2017).

Most catches are landed in fishing centers (known as *villas pesqueras*; some run by fishers' associations), which can also serve as places to process and market fish, repair and store fishing gear and equipment, and socialize and exchange information with other fishers (Valdés-Pizzini, 1990; Griffith et al. 1992). Fishers also sell to dealers, fish stores, restaurants, and hotels, and a few retail from their homes or peddle to nearby communities (Matos-Caraballo and Agar, 2011; García-Quijano et al. 2015). Geographically, the west coast is the most productive area because it has a relatively shallow and extended shelf; by contrast, the north coast is the least productive because it has a narrow insular shelf (Suarez-Caabro, 1979).

Many fishers engage in an occupational multiplicity livelihood strategy to support themselves and their families (Pérez, 2005; Griffith et al. 2007; Agar et al. 2008; García-Quijano, 2009). In addition to diversifying their livelihoods, by joining informal and formal wage labor markets, many also supplement their income with government transfer (welfare) payments (Griffith and Valdés-Pizzini, 2002; Pérez, 2005; García-Quijano, 2009).

Puerto Rico's Department of Natural and Environmental Resources (DNER) and the Caribbean Fishery Management Council (CFMC) are responsible for the conservation and management of local fisheries. DNER manages fisheries out to nine nautical miles (nmi) from the coast, and the CFMC manages those found in waters extending from nine to 200 nmi (Agar et al. 2019). Most fisheries operate under a regulated open access regime, with the exception of the deep-water snapper fishery limited entry program (i.e., cardinal and queen snappers). Fishery managers use a range of management measures, including quotas, trip limits (for queen conch), gear restrictions, seasonal and area closures, size limits, and other miscellaneous restrictions (CFMC, 2020).

3. Methods

This study used similar sampling methods to those employed in earlier DNER censuses of active commercial fishers which date back to 1988 (Matos-Caraballo and Torres-Rosado, 1989; Matos-Caraballo 1998; Matos-Caraballo et al, 2005, Matos-Caraballo and Agar, 2011). The sampling protocol required data collectors to visit fishing centers, private fish stores (known as *pescaderias*), marinas, and fishing communities several times a month for a year to identify and interview active fishers. This field intensive sampling protocol was favored over one that solely relied on DNER fishing license (or landings) frames because of the considerable turnover following María, and also because many respondents had expired fishing licenses (but had an established fishing history). Another consideration was fishers' occupational multiplicity livelihood strategies, which combine year-round or seasonal fishing with other wage labor opportunities, including some that take place in the United States (US) mainland.

An interdisciplinary team of social scientists and DNER biologists designed and implemented the data collection. Port agents from the DNER's Fisheries Research Laboratory and contracted field assistants, mainly university graduates, conducted the in-person interviews. Surveyors worked closely with heads of fishing centers, fish store owners, marina managers, and other fishery leaders to identify active fishers, including those loosely affiliated with their facilities. In total, we conducted 664 in-person, voluntary interviews, which represents 78.3% of the fishers who show up in fishery statistics following María. Approximately 30% of the respondents were from the west coast, 26% from the east coast, 25% from the north coast, and the remaining 18% from the south coast.

Consistent with other regional hurricane damage assessments, we employed the survey instrument originally designed by NMFS social scientists to investigate the one-year socio-economic impacts of Hurricane Sandy on Mid-Atlantic fisheries (Colburn et al., 2015). We slightly modified the original survey to ensure that some of the closed-ended questions better aligned with the local context. The survey was also translated into Spanish and administered on tablets using a field-enabled online program. The program securely uploaded the interviews to a cloud server. Where Wi-Fi was available, survey results were uploaded to an online platform in real time; otherwise, survey results were saved on the tablet and uploaded once internet access became available. The use of the online program lowered set-up and administration costs, reduced transcription errors, and provided ready access to the data.

The survey instrument had four sections: a) background information, b) fishing operation impacts, c) community recovery, and d) individual well-being and preparedness for future natural disasters (Colburn et al., 2015). The background information section inquired about demographics, level of education, fishing dependence, and characteristics of the fishing operation. The fishing operation impacts section asked about the reasons for suspending fishing activities, and about business-related property, fishing capital, and income losses in the 12 months following the storm. This section also inquired about changes in fishing and fishing-related practices and factors that affected the respondent's recovery.

The community recovery section asked about community changes since the storm and for the reasons behind those changes. The last section of the survey asked about respondents' perceived capability to cope with extreme weather events drawing on a series of statements. The statements inquired whether respondents believed they could secure employment outside the fisheries sector, whether they were more able to adapt than other fishers were, and whether they could continue fishing despite recurring natural disasters. For brevity, we omit these results here. This last section also asked about plans to mitigate the impact of future natural disasters. The survey instrument is available upon request from the authors.

The analysis also drew from local fishery statistics and interviews with key informants (i.e., fishery managers, heads of fishing centers, fish house owners, and fishery leaders) to help contextualize survey findings. We present both Commonwealth and coastal region (north, east, south, and west) statistics to offer additional detail.[2] The data were analyzed using descriptive and inferential statistics. One-way ANOVA, Kruskal-Wallis, and Chi square tests were used to examine for differences among coastal regions. Comparisons among regions were carried out using a Bonferroni correction to counter the effects of multiple testing. Tables report unadjusted p-values but annotations denote those p-values that are statistically significant at the 5% level after the Bonferroni correction. The data collection commenced in November 2018 and ended in November 2019.

3.1. Sample characteristics

Most respondents were experienced, middle-aged owner-operators (Table 1). Ages ranged from 16 to 89 years, with an average of 53 years. Less than 8% of the respondents were 30 years or younger. Households were highly dependent on fishing. On average, fishers derived close to 60% of their household income from fishing. In addition, fishers also participated in formal and informal wage-earning occupations such as construction, mechanical work, landscaping, and farming.

[2] The northern region extends from the municipalities of Isabella to Luquillo (Figure 3). The eastern region runs from the municipalities of Fajardo to Maunabo, including the islands of Vieques and Culebra, and the southern region stretches from the municipalities of Patillas to Lajas. The western region spans the municipalities of Cabo Rojo to Aguadilla.

Geographically, fishing dependence was highest on the west coast (72%) and lowest on the north coast (48%).

Most fishing vessels were small and equipped with a single, outboard, gasoline engine (Table 1). On average, fishers took four trips per week and devoted 33 hours per week to fishing and fishing-related activities such as maintenance and sales. About half of the respondents fished with one deckhand, whereas 17% fished alone. Fishers valued their vessels, engines and fishing equipment slightly above $18,000 on average ($12,000 median). Ninety percent of the respondents primarily fished in Commonwealth waters.

4. Results and Discussion

4.1 Immediate impacts on small-scale fisheries

Fishing activities came to a halt after María made landfall (Figure 2). In addition to wreaking havoc to the electric power infrastructure, María also disrupted petroleum shipments to the island, which comprise three-fourths of the energy consumed in Puerto Rico (EIA, 2020). Extensive damage to the transportation (roads, bridges, traffic lights) and communication infrastructure (cell phones and internet), coupled with a surge in fuel demand to fill vehicles and run generators to power homes and businesses, led to fuel rationing which resulted in long lines at gas stations that lasted for months (Palin, 2018).

Fishers reported multiple reasons for interrupting their fishing activities, of which the top three were power outages and fuel shortages (81%), customer loss (59%), and fishing capital (vessel, engine, gear, and fishing equipment) damage or loss (53%; Table 2). Without electric power to freeze and store catch and cell phone and internet service to reach customers, many fishing centers and fish stores closed forcing fishers to turn to recovery odd jobs such as clearing roads and repairing homes and businesses. A few fishers managed to continue fishing intermittingly, selling their catches along well-traveled roads or peddling them to nearby communities that had their electric service restored. Román et al (2019) explain that the recovery of electric power was slow and uneven around the island because it resulted from a combination of factors including exposure to storm forces, the quality of the local infrastructure, closeness to power stations, and the remoteness from large urban areas. For example, the municipality of Ponce in the south recovered 60% of its power within days after the storm because of recent distribution system upgrades and the addition of backup power supply (Figure 3). By contrast, the northern municipalities of Bayamon and Arecibo had to wait for three months before 60% of their power was restored.

Fuel shortages added to fishers' challenges because these drove them to take fewer and shorter trips. Additionally, even though there were price controls on fuel, some fishers claimed that fuel prices rose considerably, which made it more expensive to resume fishing. As one fisher from Arecibo described:

> *"When fuel expenses rose from $20-30 to $60 (per trip) after deducting bait and food expenses, we were left with $20 in profit, which was barely enough to scrape by, let alone maintain the boat and engine, or hire a helper."*

Power outages and fuel shortages also affected demand because few restaurants and hotels had backup generators. Additionally, for many households concerned about rebuilding their homes and livelihoods, eating out became a luxury. Table 2 shows the remaining reasons cited for suspending fishing, which included damage to coastal infrastructure (32%), preoccupations with recovery efforts (25%), unavailable crew (7%), and miscellaneous reasons (14%), such as inclement weather, poor fishing conditions, limited financial resources, sickness, and obstructed waterways.

Geographically, the reasons for suspending fishing varied significantly (Table 2). For example, on the east and north coasts, fishing capital damage ranked higher because these regions experienced higher sustained winds, heavier precipitation and more powerful surges, as María crossed the main island from Yabucoa in the southeast to Arecibo in the center north part of the island (Pasch, Penny, and Berg, 2019). On the other hand, power outages, fuel shortages, and customer base loss ranked highest on the south and west coasts because of the lower exposure to the storm, which spared local fishing fleets.

The higher ranking of power outages and fuel shortages and, to a lesser degree, customer base loss on the western and southern coasts was to some extent unexpected because these coasts experienced fewer electric service disruptions. As mentioned earlier the municipality of Ponce in the south recovered 60% of its power within days after the storm. Román et al. (2019) using nighttime satellite imagery estimated that the average number of days without electricity in southwestern districts (Ponce and Mayaguez) was less than 88 days, whereas in northeastern districts (San Juan, Humacao, and Carolina) outages exceeded 110 days. Thus, the higher ranking may have captured the spotty restoration of electrical service within these coastal regions. Damage to coastal infrastructure ranked higher on the west coast relative to other regions possibly because of the impact of late season (post-María) swells, which destroyed many already weak coastal structures. According to DNER, after María hit, the number of active fishing centers fell from 88 to 70 and 20% of the remaining centers faced severe structural issues.

4.2. One-year impacts on small-scale fisheries

4.2.1. Domestic fishery production and revenue impacts.

Six months after María hit, landings rose significantly, as electric service began to be restored to the metropolitan area, where about two-thirds of the population live (Figure 2). Purportedly, metropolitan area hotels and restaurants drove much of the uptick in seafood demand. These businesses catered mostly to emergency relief workers (who supplanted fleeing tourists) and local patrons.[3] As one fisher quipped: "*Emergency relief workers like to eat well and have 'chavos' (money)*".

Fishery statistics show that domestic landings and dockside revenues, on year-over-year basis, contracted by almost 0.4 mp (20%) and $1.4 million (15%; NOAA, 2019)[4] and that most of the losses took place on the last quarter of 2017, lending support to the claim that the recovery of the metropolitan area drove much of the surge in fishing activity. Fishery statistics also illustrate that severity of the losses varied considerably across coastal regions, target species, and gear types (NMFS, 2019).

[3] Generally, foreign visitors tend to drive much of the demand for seafood in the winter months, when most Puerto Ricans prefer eating pork and turkey, especially during the holiday season. In contrast, local residents tend to drive the demand for seafood during Lent and summer seasons when they vacation around the island.

[4] We obtain similar results when we compare post-María fishery statistics with the previous 3(5)-year average, on-year-over-year basis. Fishery statistics show that landings and revenues contracted by 0.6 (0.5) mp and $1.5 (0.8) million, respectively. Year-over-year measures are useful for cross-period comparisons because they reduce seasonality effects caused by changes in species availability and regulations (e.g., seasonal closures).

Geographically, the east coast bore the brunt of the losses. On year-over-year basis, the east coast alone accounted for 48% of the domestic landings losses and 56% of the domestic dockside revenue losses. The south and west coasts followed accounting for 23% and 19% of the production losses, respectively, and 14% and 17% of the forgone revenues, respectively (NMFS, 2019). In terms of species, 75% of the revenue losses were concentrated on six species: queen conch (27%), yellowtail snapper (15%), spiny lobster (14%), lane snapper (7%), dolphinfish (6%) and queen snapper (6%; NMFS, 2019).

Among the hardest hit gear types were fish and lobster traps, handlines, skin and scuba diving and bottom lines, which accounted for 32%, 21%, 19% and 12% of the domestic revenue losses, respectively (NMFS, 2019). Most of the trap and handline revenue losses occurred on the heavily impacted east coast, while most of the skin and scuba diving revenue losses occurred on the west and north coasts, where damaged inshore habitats (algal plains and seagrass meadows) reportedly pushed queen conch into deeper waters.

Respondents reported losing around 6,700 traps (including fish, lobster, and deep-water snapper traps). About 55% of these losses occurred on the east coast, 23% on the south coast, 11% on the north coast and the remaining 9% on the west coast. Although DNER considered that the reported losses were high, it acknowledged that many illegal, low-cost, makeshift plastic traps (essentially repurposed milk crates) washed ashore after the storm. Conservación ConCiencia, a local conservation non-governmental organization, which ran a derelict fishing gear removal program, reported that it had removed 826 lost traps (over two years) following the storm, of which 74% were made of plastic, which are illegal (R. Espinoza, 2020, pers. comm.). Conservación ConCiencia paid fishers $100 per trap retrieved (around $500 per trip).

When asked about the reasons for the heavy gear losses, fishers explained that they left their gear in the water because they were busy working on storm preparations, there were limited (if any) land storage options available, and the size of their vessels was often too small relative to the amount of gear deployed. Fishers further explained that as the storm got closer, winds and currents picked up making it unsafe and harder to locate and retrieve their gear, especially traps. Key informants felt that many fishers had become a little too complacent because Irma had skirted the island only a few weeks earlier. Key informants also noted that fishers were blindsided by the heavy swells and extensive flooding, which washed out to sea fishing gear and miscellaneous equipment stored in fishing centers.

4.2.2. Economic and employment losses

4.2.2.1. Fishing operation losses

The most dramatic and lingering impacts of natural disasters pertain to the loss of productive assets and livelihoods (Carter et al, 2006, Van den Berg, 2010). María caused considerable damage to fishing operations (including buildings and docks) and significantly reduced households' fishing income. Eighty percent of the respondents reported damage to their fishing operations, which included both fishing capital and shoreside structures.

Self-reported economic losses from damaged fishing capital and shoreside infrastructure ranged from zero to $200,000, averaging about $8,600 ($3,000 median; Table 4). Average economic losses ranged from $3,900 ($1,000 median) on the west coast to about $12,400 ($6,000 median) on the east coast. Ninety-four percent of the respondents had no insurance. Multiplying the average uninsured loss by the number of fishers (1,013), who appear in fishery statistics the year prior to María, suggests that damages totaled around $8.8 million dollars.

4.2.2.2. Forgone fishing income

Eighty-two percent of the fishers surveyed said that they had resumed fishing regularly but were operating below full capacity (at an average of around 70%). Fishers reported that, on average, their annual fishing income had contracted by $8,800 ($5,000 median; Table 4). The severity of the losses varied regionally ranging from an average of $5,500 on the south coast to $13,300 on the east coast. Fishers' finances suffered mainly because of the extended power outages and fuel shortages (81.2%), weak seafood sales (57.9%), damaged fishing capital and coastal infrastructure (53.5%), and access restrictions to fishing boats, docks, or other infrastructure necessary for fishing (27.9%; Table 3).

Multiplying the average forgone fishing income by the number of fishers, who appear in fishery statistics the year prior to María, suggests that total income losses were around $9 million dollars. This forgone income estimate is several magnitudes higher than the forgone dockside revenues ($1.4 million) derived from the fishery statistics discussed earlier (NMFS, 2019). The large difference is probably the result of a combination of factors such as the failure to report and record fishing activities in the early months after María's landfall, recall bias, and the inadvertent conflation of out of pocket, fishing-related expenses as forgone income.

4.2.2.3. Employment losses

With scarce food and utilities, damaged homes, and dire recovery prospects, there was an exodus of Puerto Rican residents to the US mainland, particularly to the State of Florida. Hinojosa and Meléndez (2018) estimated that one year after María made landfall about 160,000 Puerto Ricans fled to the US mainland, which was about the combined net out-migration flow of the previous two years. Echenique and Melgar (2018) using cell phone usage data determined that 400,000 people left for the US mainland after María, but most of them returned four months later. This temporary migration probably gave many a respite from their daily hardships and provided an avenue to secure employment and governmental assistance outside the island.

Although, there is uncertainty about the number of fishing jobs lost, fishery statistics documented 165 fewer fishers (16.3%) the year following María (NMFS, 2019). Captains accounted for about 79% of these job losses and deckhands for the rest. More recent fishery statistics show a resurgence in the number of captains (about 130), underscoring the importance of occupational multiplicity as a means to cope with livelihood disruptions and to rebuild fishing operations, if necessary. Fishers' return once the economy began improving suggests a high regard for the fishing lifestyle. Many attributes of the fishing lifestyle such as independence, adventure, enjoyment of the natural environment, and healthfulness/therapy are seldom found in other occupations (Pollnac and Poggie, 2008; García-Quijano et al, 2015; Partelow et al, 2020). The pursuit of the fishing lifestyle has also been tied to increases in job and life satisfaction as well as well-being (Pollnac and Poggie, 2006; Pollnac et al, 2014; García-Quijano et al, 2015; Seara et al, 2017)

Numerous studies have shown that fishers' high levels of job satisfaction explain their strong occupational attachment and reluctance to leave the fishery even in the face of economic uncertainty (Pollnac and Poggie, 2006; Pollnac and Poggie, 2008; García-Quijano et al, 2015, Seara et al, 2017; Partelow et al, 2020). However, in our study, limited employment opportunities outside the fishery may have also conditioned fishers' occupational choice. Table 7 shows that 71% of the respondents said that was it very hard or hard to find a non-fishing job owing to a number of reasons, including the protracted economic downturn, limited formal education, age and health reasons. These results are consistent with work by Seara et al (2016) who showed that commercial fishers following a natural disaster felt less confident (relative to other groups) about their ability to earn a living outside the fishery.

When we inquired about the fate of deckhands, heads of fishing centers mentioned that many had returned from the US mainland a few months after María because of their limited formal education and lack of certifications to pursue trade jobs. Ninety percent of the respondents reported having their operations return to pre-María workforce levels, which took them, on average, about 5.5 months (4 months median). Only 3.2% of the respondents reported downsizing operations mainly because of crew unavailability (migration, working elsewhere) and affordability issues.

4.2.3. Changes in fishing and fishing-related practices

Changing fishing and fishing-related practices such as retrofitting fishing vessels and shifting gears to target different stocks or switching homeports to pursue market opportunities can be useful strategies to moderate the impacts of natural disasters (Buck, 2005). However, few fishers reported adjusting their fishing and fishing-related practices probably because many of these are finely tuned to local ecological conditions and occupational multiplicity strategies (García-Quijano, 2009). In addition, significant departures from current fishing practices require substantial investments and knowledge of other fisheries, which many fishers lacked.

Only 10% of the fishers reported that they had relocated all (or part) of their fishing operations (Table 4). Most of the reported changes involved switching landing and/or marketing locations because of infrastructure damage. For instance, Cruz Torres et al. (nd) report that fishers from Maunabo launched from Yabucoa because the strong tides made it unsafe to load and unload from their deteriorated home ramp. There were also reports of displaced fishers operating from neighboring fishing centers (e.g., ‘Playa Tres Hermanos’ in Añasco) and marinas (e.g., Puerto del

Rey Marina in Fajardo) where they could not only launch their craft but also market their catches. These cooperative ventures and accommodations point to the importance of social capital in the recovery process (Clay et al. 2016). Social capital is an all-encompassing concept that captures the strength of social ties, the degree of trust, and norms of reciprocity that facilitate collaboration among individuals and groups of individuals (Grafton, 2005). García-Quijano (2009) observes that cultivating social ties through community reciprocity and solidarity is an important mechanism for managing risk and uncertainty in dynamic and heterogeneous social-ecological systems. However, Marín et al (2015) warn that relying solely on social relations may be insufficient because other factors such as the extent of the damages and geographical isolation can play a decisive role shaping the recovery of livelihoods.

While close-knit ties and shared values of mutual help eased relocation into new fishing centers and marinas, we also found evidence that identity and a sense of control played an important role in fishers' decision to remain operating in their communities, even in cases where facilities were severely damaged (Uscher-Pines, 2009). For instance, in fishing center 'Villa del Ojo' in Aguadilla, fishers continued to operate from their destroyed facility because they were worried that if they left, they would not be allowed to return because zoning regulations prohibit rebuilding on eroded beaches (Photo 1). In addition, the high value of adjacent properties made rebuilding the facility nearby unfeasible. Fishers' also feared that if they abandoned the site, the municipal government would build tourism and recreational facilities.

In addition to switching landing and marketing locations, many fishers moved to new fishing grounds because of pollution concerns as many sewage treatment plants remained out of service for months. Fishers from fishing center 'Jarealitos' in Arecibo, for example, reported that the heavy untreated runoff from the Camuy water treatment plant and the Arecibo river had coated nearshore hard bottom areas with a thick layer of toxic mud (6-8 inches) forcing them to fish further west off the coast of Quebradillas (Figure 3).

Storm-related habitat degradation was another important reason for switching fishing grounds and adjusting the catch composition. DNER officials and key informants reported that divers began targeting queen conch in deeper waters after María damaged inshore algal plains and seagrass meadows; this resulted in at least six divers receiving hyperbaric treatment for decompression sickness. To compensate for the lower queen conch catches, many divers reportedly caught more spiny lobsters. Fishers from Naguabo claimed that the loss of seagrasses was responsible for a disappointing octopus season. Only a handful of fishers mentioned transitioning to other gears mainly from traps to handlines.

4.2.4. Factors that influenced fisher recovery

Like most Puerto Ricans, fishers struggled to recover because of the sluggish governmental response that left them without electricity, communications, clean water, and medical services for months. Fishers identified power outages and fuel shortages (80%) as the most significant barrier to their recovery, followed by financial burdens (54%; Table 5). Of note is that financial difficulties were, on average, less of a concern on the west coast. This is probably because of the lower exposure to the storm and the fewer electric service disruptions, which facilitated a swifter recovery of local markets and livelihoods. The importance of re-establishing markets has been reported elsewhere; for instance, Marín et al (2010) stressed the need to bring back tourism to help restore the livelihoods of small-scale fishers after the 2010 tsunami in Chile.

Other factors that interfered with fishers' recovery had to do with the difficulties of finding time to obtain assistance (37%) which was likely tied to busy workloads and shifting schedules and the few job opportunities outside the fishery (34%; Table 4). Other obstacles included the limited progress rebuilding coastal (29%) and terrestrial (24%) infrastructure and delays obtaining construction permits (10%).

Despite the slow recovery, fishers overcame many obstacles with the support of family and friends (53%) and personal finances and labor (45%, Table 6). Forty-two percent ranked the support of family and friends as the most important reason for their recovery stressing the importance of 'bonding' social capital, which relates to strong ties within groups of individuals, who share similar backgrounds and interests, and can provide emotional and material support. Other studies have also documented the importance of social bonds following natural disasters (Ingles and McIlvaine-Newsad, 2007; Aldrich and Sawada, 2015; Clay et al. 2016).

When we asked about the type of assistance that family and friends provided, fishers explained that they received emotional support (empathy, compassion, and a feeling of emotional closeness) and physical assistance in clearing debris, repairing homes, and fixing fishing equipment. Several fishers mentioned that they received remittances from relatives in the US mainland to help with the home and boat repairs and to purchase generators. Fishers also reported working on each other's boats, engines, and gear as well as pooling financial resources to continue fishing. Several heads of fishing centers reported that they took it upon themselves to research and disseminate information on local and federal disaster relief programs and sometimes even process their members' financial assistance paperwork. Heads of fishing centers also worked with religious, charitable and other non-governmental organizations coordinating donations.

The ability of heads of fishing centers to tap into additional resources underscores the importance of other types of social capital, namely 'bridging' and 'linking' social capital, which may explain why recovery rates among fishing communities varied (Ingles and McIlvaine-Newsad 2007; Aldrich, 2012; Clay et al. 2016; Sadri et al. 2018). Bridging social capital refers to connections across similar, but different, social networks such as local churches and civic groups, whereas linking social capital denotes connections (or engagement) across dissimilar social networks, but at different hierarchies such as government agencies (Grafton, 2005). Hawkins and Maurer (2010) suggest that bonding social capital is important to obtain timely support, whereas bridging and linking social capital provide paths for long-term survival and community renewal.

Notwithstanding logistical difficulties, poor dissemination of aid information, and delays dispersing relief assistance, fishers acknowledged the assistance of various government agencies (e.g., Puerto Rico's Department of Agriculture, PR DoA, and the Federal Emergency Management Agency, FEMA) and safety net programs (e.g., the Federal Disaster Unemployment Assistance Program, DUA in Spanish, and the Nutrition Assistance Program, PAN or *cupones* in Spanish). Fishers also provided suggestions to improve the efficacy of some of these programs. For example, some fishers believed that PR DoA's fishing assistance voucher program was burdensome and unfair. The program required fishers to make out of pocket purchases of fishing equipment and materials ($350 to $1000) before requesting reimbursement, straining their already-stretched finances. In addition, independent fishers complained that fishers affiliated to fishing centers were the only ones that benefited from the vouchers. Fishers also acknowledged the support of churches, charitable and non-governmental organizations (many from the US mainland and diasporic communities), which not only provided water, food and other essential supplies but also, in some cases, gasoline, fishing supplies (e.g., wire for traps), and even engines and fishing vessels.

4.2.5. .Community vulnerability and preparedness for future natural disasters.

Natural disasters pose a major threat to fishers, their families and communities and since these events will likely continue to increase in number and severity, it is useful to understand how María influenced fishers' perceptions about community vulnerability and their plans to contend with future natural disasters (Nelson et al. 2007). Almost two-thirds of the fishers believed that their communities had become more vulnerable to coastal hazards because of María (Table 7). There were no statistically significant perception differences among coastal regions, nor were there statistically significant correlations with the demographic and fishing operation variables, suggesting that this is a widely held belief. Beliefs about increased community susceptibility to coastal hazards rested on perceptions of increased exposure to severe weather (storms, surges, and floods) and its impacts on coastal habitats (beach and dune erosion, mangrove losses), as well as the slow recovery of damaged coastal infrastructure (seawalls, ramps). On the other hand, fishers who believed that their communities had become less susceptible to coastal hazards pointed to recent coastal infrastructure and home improvements and lessons learned from María.

The survey concluded asking about plans to deal with future natural disasters such as María. Fishers reported that home preparedness plans revolved around preventive and damage-mitigating measures such as devoting more time to home preparations, stockpiling water, food, and fuel, installing hurricane shutters, reinforcing homes with concrete, and purchasing electric generators, water cisterns, and solar panels to ride out the aftermath of the storm. Similarly, fishing operation preparedness plans hinged on better safeguarding of boats and fishing equipment, promptly removing gear from the water, setting aside funds for contingencies, moving freezers and coolers to higher ground, and storing fuel. Community preparedness plans revolved around obeying advice and evacuation orders from public officials, picking up debris and liter before and after the storm, and helping neighbors, particularly the elderly.

5. Conclusions

María was one of the most devastating hurricanes in recent history causing extensive damage to fishers' livelihood assets and income sources. Despite the substantial damage to fishing capital and shoreside infrastructure, fishers emphasized that the extended power outages, fuel shortages, and the loss of clients were the most significant hurdles to their recovery. Most of the fishing activity was able to rebound once electric service became widely available around the island, particularly in the metropolitan area. Losses to the small-scale fishing sector were estimated be around $17.8 million excluding the impacts to the seafood processing and marketing sectors. Damaged and lost fishing capital and fishing-related infrastructure accounted for 51% of these losses and forgone fishing income for the remaining 49%.

The study also found that there were few changes in fishing and fishing-related practices following María, and these mainly involved switching landing and marketing locations, underscoring the importance of occupational multiplicity strategies as a means to cope with natural disasters. For many the flexibility to diversify into other occupations, either locally or on the US mainland, not only provided relief from their hardships and losses but also provided them an avenue to reinsert themselves into fishing when economic conditions improved. Close-knit familial and communal ties and shared values of mutual help, denoted as social capital, also played an important role in the recovery process by mobilizing and providing access to scarce resources.

Whether Puerto Rican fishing communities successfully transition from short-run, reactive coping strategies to long-run adaptive strategies that address future disasters remains to be seen. Nevertheless, the transition will undoubtedly require expanding the current approach that is focused on rebuilding productive assets to a more encompassing approach that fosters the ability of communities to organize and act collectively and learn to recognize and respond to change (Cinner et al 2018).

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Disclaimer

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Table 1: Demographic and vessel characteristics by coastal region.

	East coast	North coast	South coast	West coast	Puerto Rico	N	p-value
Number of fishers (count)	175	168	119	202	664	664	-
Age (yrs)	52.1 (14.2)	54.6 (14.3)	54.2 (15.2)	50.9 (14.4)	52.7 (14.5)	661	0.0908
Household income from fishing (%)	48.9 (36.0)	48.2 (31.3)	62.9 (32.6)	71.8 (29.5)	58.6 (33.8)	601	-†
Number of trips per week (count)	3.4 (1.7)	3.3 (1.4)	3.8 (1.5)	4.1 (1.5)	3.6 (1.6)	655	<.0001
Time spent on fishing-related activities (hrs/wk)	40.5 (22.7)	35.9 (19.9)	35.0 (18.8)	26.3 (17.2)	33.1 (20.1)	537	<.0001
Vessel length (ft)	20.8 (3.8)	20.0 (3.5)	20.9 (7.2)	20.3 (4.6)	20.5 (4.8)	578	0.1128
Engine propulsion (hp)	117.2 (97.1)	107.6 (83.8)	80.6 (75.4)	97.7 (94.0)	101.7 (89.6)	572	<.0001
Value of vessel(s), engine(s), and fishing equipment ($)	20,833.4 (26,097.1)	22,117.7 (42,256.2)	11,063.1 (10,476.1)	16,748.3 (18,817.7)	18,123.1 (27,915.2)	567	0.0002

Mean and standard deviation in parentheses, unless otherwise noted. One-way ANOVA and Kruskal-Wallis (when the normality assumption was not met) tests were used to test for differences among coastal regions. † Assumptions of normality and equal variances were not met.

Table 2: Reasons for suspending fishing activities (check all that apply).

Reasons for suspending fishing activities (%)	East coast	North coast	South coast	West coast	Puerto Rico	N	p-value
Power outages & gas shortages	66.3	78.6	91.5	89.9	81.0	658	<.0001‡
Soft seafood demand	45.1	55.4	60.2	72.6	58.7	658	<.0001‡
Fishing capital damage	64.6	60.7	50.9	37.6	53.0	658	<.0001‡
Damage coastal infrastructure	24.0	25.6	31.4	44.2	31.8	658	<.0001‡
Busy with recovery efforts	26.3	28.0	28.8	17.8	24.6	658	0.0606
Unavailable crew	9.7	6.0	9.3	3.6	6.8	658	0.0732
Other reasons	16.0	22.6	7.6	9.6	14.3	658	0.0005‡

χ^2 tests were used to test for differences among coastal regions. ‡Statistically significant regional differences using Bonferroni correction for multiple comparisons ($p<0.05$).

Table 3: Reasons for losing revenue (check all that apply).

Reasons for losing revenue (%)	East coast	North coast	South coast	West coast	Puerto Rico	N	p-value
Power outages & gas shortages	74.4	79.8	88.2	84.0	81.2	655	0.0169
Soft seafood demand	51.5	50.3	57.6	69.7	57.9	646	0.0004‡
Fishing capital & infrastructure damage	69.8	60.0	52.5	34.4	53.5	647	<.0001‡
Access limitations	23.6	23.6	29.9	33.9	27.9	635	0.0861
Unavailable crew	6.2	7.9	12.0	1.6	6.3	634	0.0025‡
Poor fishing conditions	43.0	35.5	47.0	34.0	39.1	639	0.0692
Environmental and habitat damage	11.2	16.9	26.3	19.4	17.9	636	0.0119

χ^2 tests were used to test for differences among coastal regions. ‡Statistically significant regional differences using Bonferroni correction for multiple comparisons ($p<0.05$).

Table 4: Shoreside infrastructure damages and fishing income losses.

	East coast	North coast	South coast	West coast	Puerto Rico	N	p-value
Fishers reporting infrastructure damages and/or fishing income losses (%)	94.2	91.5	68.5	60.4	79.7	615	<.0001‡
Fishing operation and shoreside infrastructure damages ($)	12,416.1 (21,153.0)	11,605.1 (22,705.7)	5,055.8 (12,573.6)	3,904.7 (7,938.9)	8,617.3 (18,030.4)	596	<.0001‡
Forgone fishing income ($)	13,332.8 (28,615.3)	9,096.3 (18,077.0)	5,481.0 (5,812.6)	6,898.9 (8,847.6)	8,842.2 (18,152.8)	498	0.0040‡
Relocated all or part of fishing operation (%)	13.8	8.4	5.2	9.5	9.6	646	0.0953
Plans to relocate all or part of fishing operation (%)	6.9	8.4	2.6	4.7	5.9	645	0.1815

Mean and standard deviation in parentheses, unless otherwise noted. χ^2 and Kruskal-Wallis tests were used to test for differences among coastal regions. ‡Statistically significant regional differences using Bonferroni correction for multiple comparisons ($p<0.05$).

Table 5: Factors that impeded personal recovery (check all that apply).

Factors (%)	East coast	North coast	South coast	West coast	Puerto Rico	N	p-value
Power outages and fuel shortages	74.7	80.2	88.1	79.0	79.9	650	0.0473
Lack of financial resources	58.5	59.2	58.1	41.6	53.6	642	0.0013‡
Lack of time to get assistance	34.6	43.9	39.7	30.2	36.6	631	0.0481
Lack of employment opportunities	31.5	38.4	34.5	33.2	34.3	632	0.5915
Damaged coastal infrastructure	21.7	35.8	20.7	32.8	28.5	631	0.0045‡
Damaged terrestrial infrastructure	27.3	25.0	27.6	17.7	23.9	628	0.1097
Other reasons	14.7	11.0	9.5	11.3	11.8	629	0.5528
Lack/delay getting construction permits	3.7	6.1	6.0	22.8	10.5	630	<.0001‡
Unavailable crew	5.0	4.9	8.6	4.3	5.4	627	0.4027
Zoning, ordinances, etc.	1.9	3.1	0.9	5.3	3.0	630	0.1158

χ^2 tests were used to test for differences among coastal regions. ‡Statistically significant regional differences using Bonferroni correction for multiple comparisons ($p<0.05$).

Table 6: Factors that supported personal recovery (check all that apply).

Factors (%)	East coast	North coast	South coast	West coast	Puerto Rico	N	p-value
Family and/or friends	54.9	63.5	50.4	44.0	53.0	661	0.0024[‡]
Personal finances and labor	36.6	50.9	55.5	40.5	44.8	661	0.0026[‡]
NAP/Food stamps	27.4	29.9	41.2	34.0	32.5	661	0.0773
PR Department of Agriculture	24.6	15.6	27.7	21.0	21.8	661	0.068
FEMA	20.0	18.0	23.5	19.5	20.0	661	0.7075
Other reasons	17.7	14.4	17.7	10.5	14.7	661	0.1772
Church	23.4	17.4	11.8	5.5	14.4	661	<.0001[‡]
Disaster unemployment assistance (DUA)	14.3	12.6	15.1	12.5	13.5	661	0.8834
Pension	18.3	12.6	16.0	7.0	13.0	661	0.0088
Community groups	19.4	18.6	9.2	4.5	12.9	661	<.0001[‡]
NGOs	14.9	4.8	0.8	6.0	7.1	661	<.0001[‡]
Crew	8.0	5.4	5.0	1.0	4.7	661	0.0141
Bank loan	0.6	2.4	3.4	4.0	2.6	661	0.1919

SBA	1.7	1.2	2.5	2.5	2.0	661	0.788

χ^2 tests were used to test for differences among coastal regions. ‡Statistically significant regional differences using Bonferroni correction for multiple comparisons ($p<0.05$).

Table 7: Perceptions about employability outside the fishing sector and community vulnerability to coastal hazards.

Perception (%)	East coast	North coast	South coast	West coast	Puerto Rico	N	p-value
Access to non-fishing jobs (%)							
Very hard or hard	65.61	69.2	73.3	76.6	71.4	621	0.2431
Neither hard nor easy	17.8	15.4	10.7	13.8	14.7		
Very easy or easy	16.6	15.4	16.1	9.7	14.0		
Community vulnerability to coast hazards (%)							
More vulnerable	63.3	67.9	62.0	67.0	65.3	629	0.6633
Less vulnerable or same	37.7	32.1	38.0	33.0	34.7		

χ^2 tests were used to test for differences among coastal regions. ‡Statistically significant regional differences using Bonferroni correction for multiple comparisons ($p<0.05$).

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Figure 1: Map of the Commonwealth of Puerto Rico.

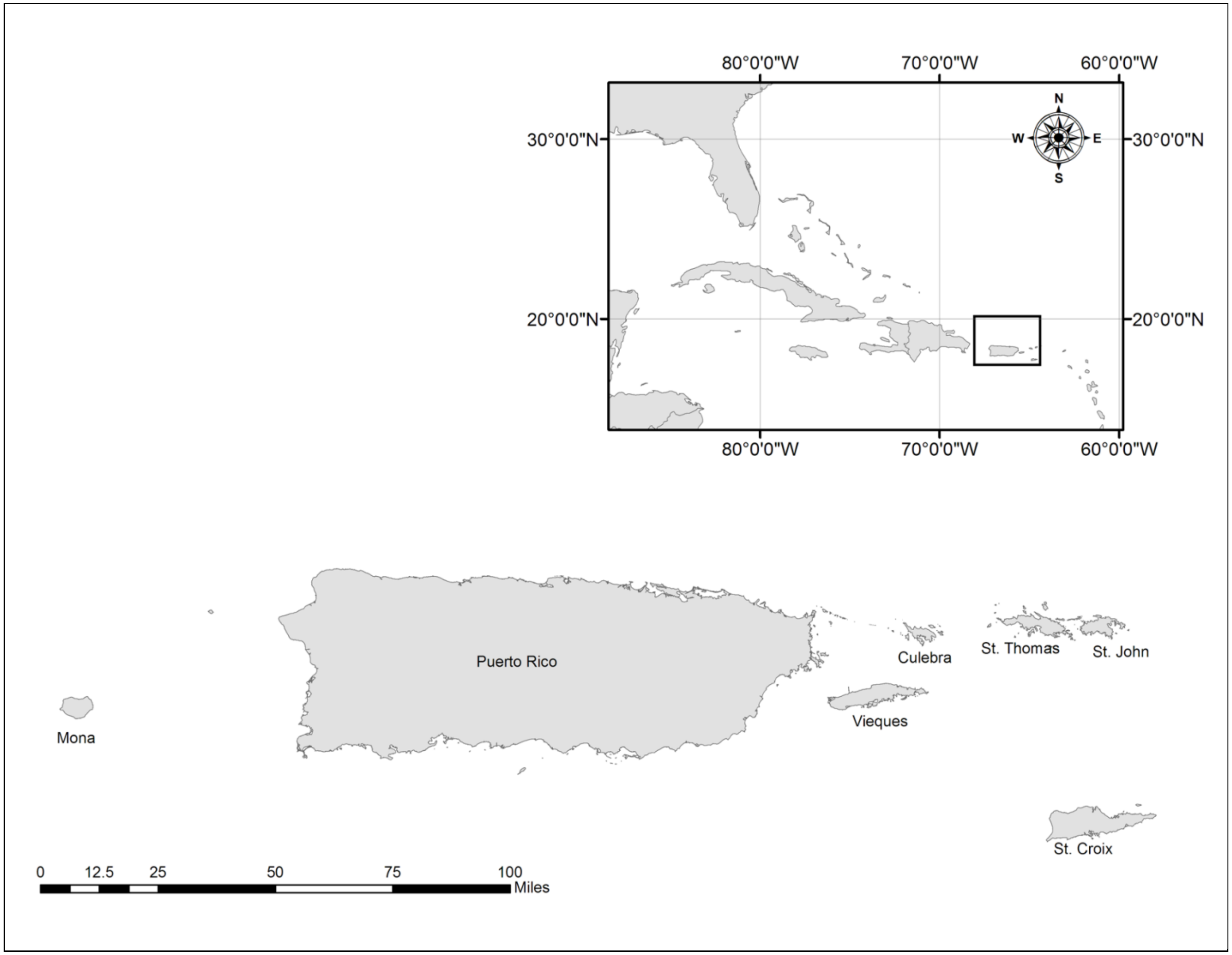
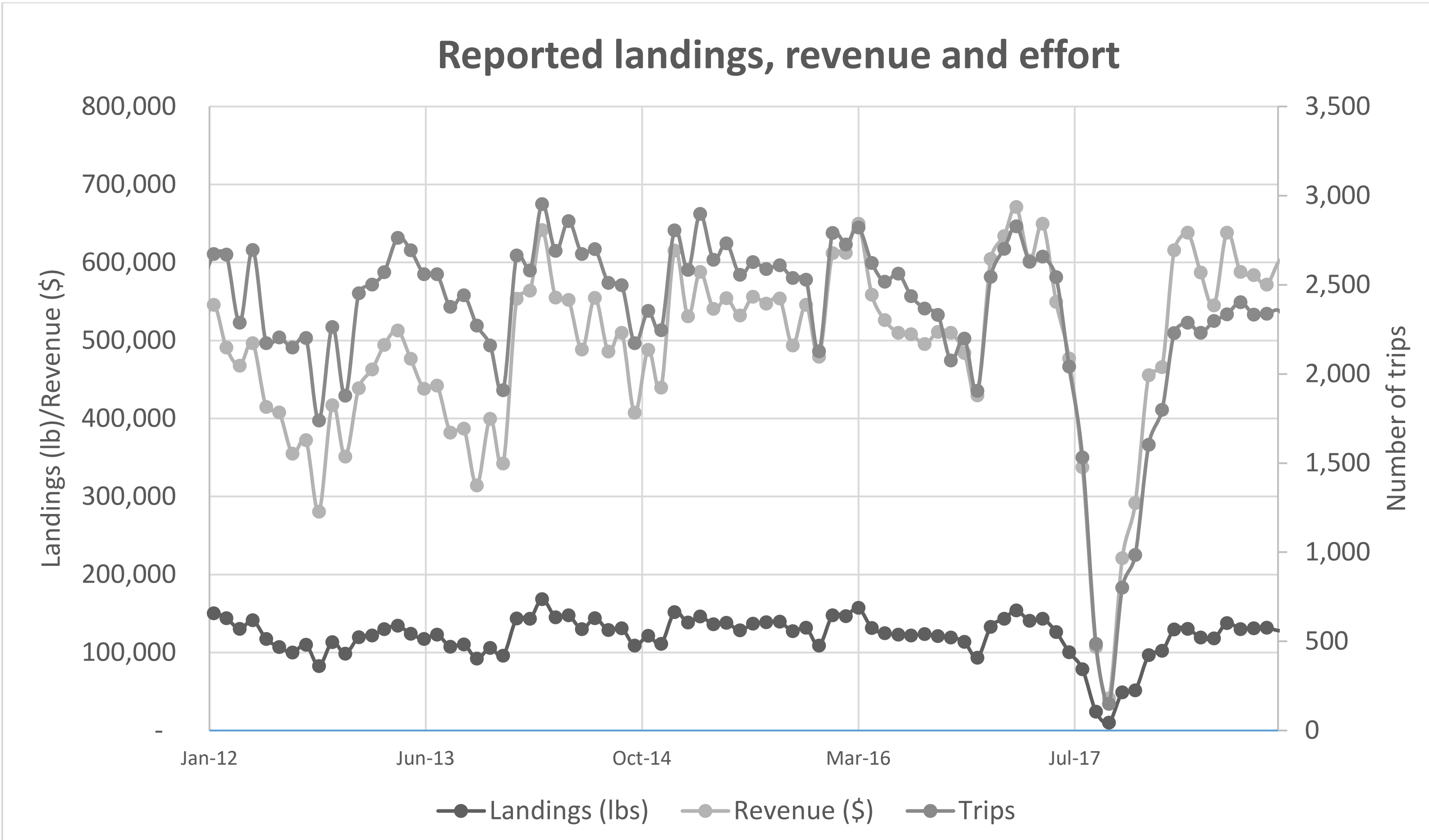


Figure 2: Puerto Rican monthly self-reported landings, nominal dockside revenues, and number of trips.



Source: NOAA, 2019.

Figure 3: Map of the municipalities in the Commonwealth Puerto Rico.

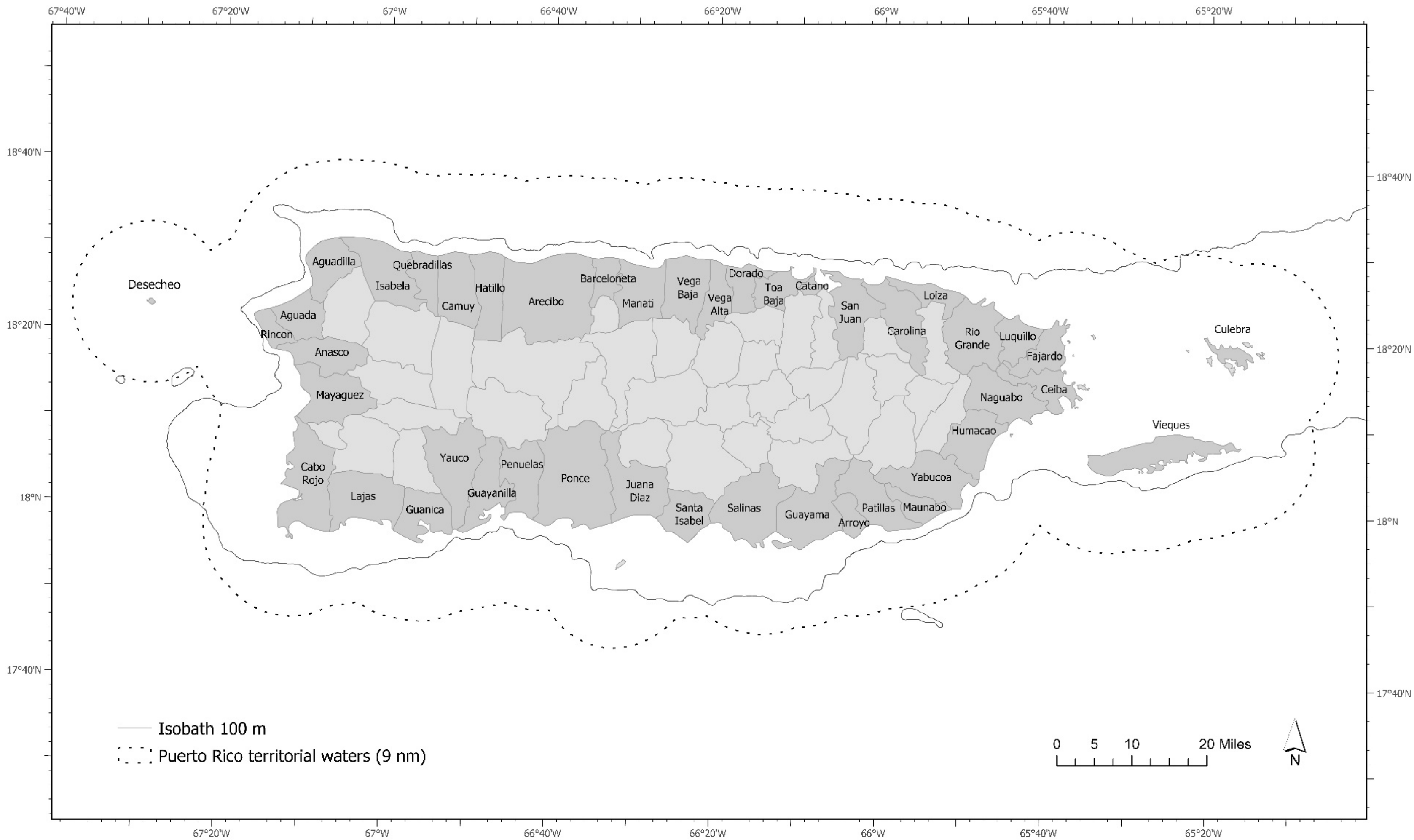


Photo 1: Damaged facilities in fishing center 'Villa del Ojo', Aguadilla.