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ARTICLE

The Commercial Trap Fishery in the Commonwealth of Puerto Rico: an Economic, Social, and Technological Profile

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Abstract
In this paper, we describe the socioeconomic conditions of the small-scale trap fishery in the Commonwealth of Puerto Rico and examine the determinants affecting the technical performance of the fleet. The socioeconomic data used in the analysis were derived from random, in-person interviews with 50 trap fishers, which accounted for about one-third of the active trap fishers. The study found that the fishery is composed of middle-aged, small-scale commodity producers who use traditional, capital-intensive technologies to target Caribbean spiny lobsters *Panulirus argus* and various reef fishes. Fishers reported that fishing made up 74% of their household income. We also explored the factors influencing the technical efficiency of the fleet by using a stochastic production frontier model. The analysis suggested that trap operations could increase their gross revenues per trip by 36%, on average, by using current input levels and technology more efficiently. The fleet exhibited decreasing returns to scale. The study also found that a 10% increase in the number of traps tended would raise gross revenues by 0.9% and that baiting traps would raise gross revenues by 1.4%. The analysis suggested that fishing experience and kinship ties were the key determinants of technical efficiency. We also explored the policy implications stemming from these results.

The trap fishery is the quintessential small-scale fishery that has long provided sustenance, income, and employment to many fishing communities throughout the Commonwealth of Puerto Rico (Agar et al. 2008). Traps are popular because they can be fished year-round with little attention, which permits fishers to engage in other economic endeavors. In addition, fishers with health issues and safety concerns favor traps because they can be handled with relative ease from small vessels (Jarvis 1932; Whiteleather 1971; Sylvester and Dammann 1972; Agar et al. 2008). Family tradition also plays a role in the sustained use of traps. Today, trap fishers report annual landings of roughly 0.25 million lb of shellfish and finfish worth about US$1 million in dockside revenues (NMFS 2016).

Despite having been the most prominent gear for decades, traps have lost ground to other fishing gears in recent years. Commercial trapping's share of overall landings (by weight) fell from 40% in 1983 to 15% in 2014, whereas the share of landings obtained by commercial diving rose from 21% to 31% during the same period. Nonetheless, traps remain popular among small-scale fishers who live in rural communities,

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especially on the south coast, which has among the highest unemployment and poverty rates in Puerto Rico. These low-income fishers traditionally have combined diverse occupations with fishing to eke out a living (Jarvis 1932; Griffith et al. 2007; Matos-Caraballo and Agar 2011). Trap fishing is also popular on the south coast because it has a productive platform and is less exposed to storms relative to other regions, such as the north coast (Jarvis 1932; Matos-Caraballo and Agar 2011).

Development of policies to advance the welfare of small-scale fishers requires an understanding not only of the fishery's economic and social conditions but also of the technological factors that may hinder the pursuit of improved livelihoods. Securing efficiency gains can assist fishing communities in meeting their long-term income, sustenance, and employment needs provided that management agencies can maintain harvest levels commensurate with the productivity of the stocks (Pinello et al. 2016). Against this backdrop, the present study had two main objectives. The first objective was to describe the social and economic conditions of the small-scale trap fishery in Puerto Rico. The absence of up-to-date information is a significant obstacle in the development and evaluation of management proposals. The second objective was to assess the factors that drive the technical efficiency (TE) of trap operations. Other than the now-dated work by Abgrall (1974), little attention has been paid to TE issues. Studies that are focused on TE can shed light on the factors that constrain the harvesting potential of fishing operations, which can play an important role in alleviating poverty. Moreover, Oliveira et al. (2016) observed that the use of social variables to analyze the performance of small-scale fleets has been fairly limited in the literature due to the absence of detailed data. Our study also contributes to a small but growing body of literature examining factors that affect the TE of small-scale fisheries (Fousekis and Klonaris 2003; Squires et al. 2003; Esmaeili 2006; Sesabo and Tol 2007; Akanni 2010; Oliveira et al. 2010, 2016; Pinello et al. 2016).

METHODS

Data.—The data came from voluntary, in-person interviews with 50 active trap fishers, about 36% of the population of trap fishers. The trap fishers were interviewed by using a standardized survey instrument that contained both closed- and open-ended questions. Fishers were asked about household demographics, capital investment in boats and equipment, fishing practices, revenue and cost structure, remunerative arrangements, and crew organization and recruitment (Table 1). The survey instrument is available from the authors upon request.

The sample was stratified by coastal region to capture the range of operations and to make the survey easier and more cost-effective to implement (Figure 1). If current contact information (e.g., a phone number) was available, trained interviewers were instructed to set up meetings at times and places that were most convenient to the fishers. Otherwise, interviewers attempted to reach them at the local fish cooperative and/or dock. To satisfy the requirements of the sampling protocol, interviewers were instructed to draw a replacement fisherman only if the randomly selected fisherman (1) refused to participate in the survey; (2) was unavailable due to illness, travel, or death; or (3) could not be contacted after six separate attempts. No compensation was provided for participating in the survey. Canvassing took place between June 2014 and January 2016; however, during that period, we concurrently surveyed fishers who used hook-and-line gear and scuba gear. The purpose of these attendant data collections was to provide a socioeconomic profile of these other fishing gears (see Agar and Shivlani 2016, in press). In addition to interviewing trap fishers, we conducted semi-structured interviews with key informants to help us contextualize our findings. Key informants included fishery managers, port agents, and professionals involved in research and outreach.

Model.—In addition to describing the present socioeconomic condition of the fishery, we examined the levels of TE of the small-scale trap fleet by using a stochastic distance production frontier (SPF) model. These models are useful for examining the technical performance of fishing vessels. The SPF method defines a maximum potential output (or "best-practice") frontier that is used to benchmark the production of individual vessels. Vessels that produce below the best-practice frontier are deemed inefficient (Solís et al. 2015). To avoid capital heterogeneity biases, the analysis focused exclusively on operations that used fish traps, which reduced our sample from 50 to 44 observations.

An attractive feature of SPF models is that they do not require explicit behavioral assumptions about the economic motivations of the fisher (e.g., profit maximization or cost minimization) since the method is focused on whether the available inputs are fully utilized given the existing technology. Additionally, SPF models allow for

TABLE 1. Number of contacts, nonresponses, and completed interviews with trap fishers in each coastal region of Puerto Rico.

Regions	Trap population	Target number of interviews	Number of completed interviews	Number of nonresponses	Number of contacts
East coast	44	16	16	15	31
North coast	14	5	5	3	8
South coast	53	19	19	15	34
West coast	28	10	10	15	25

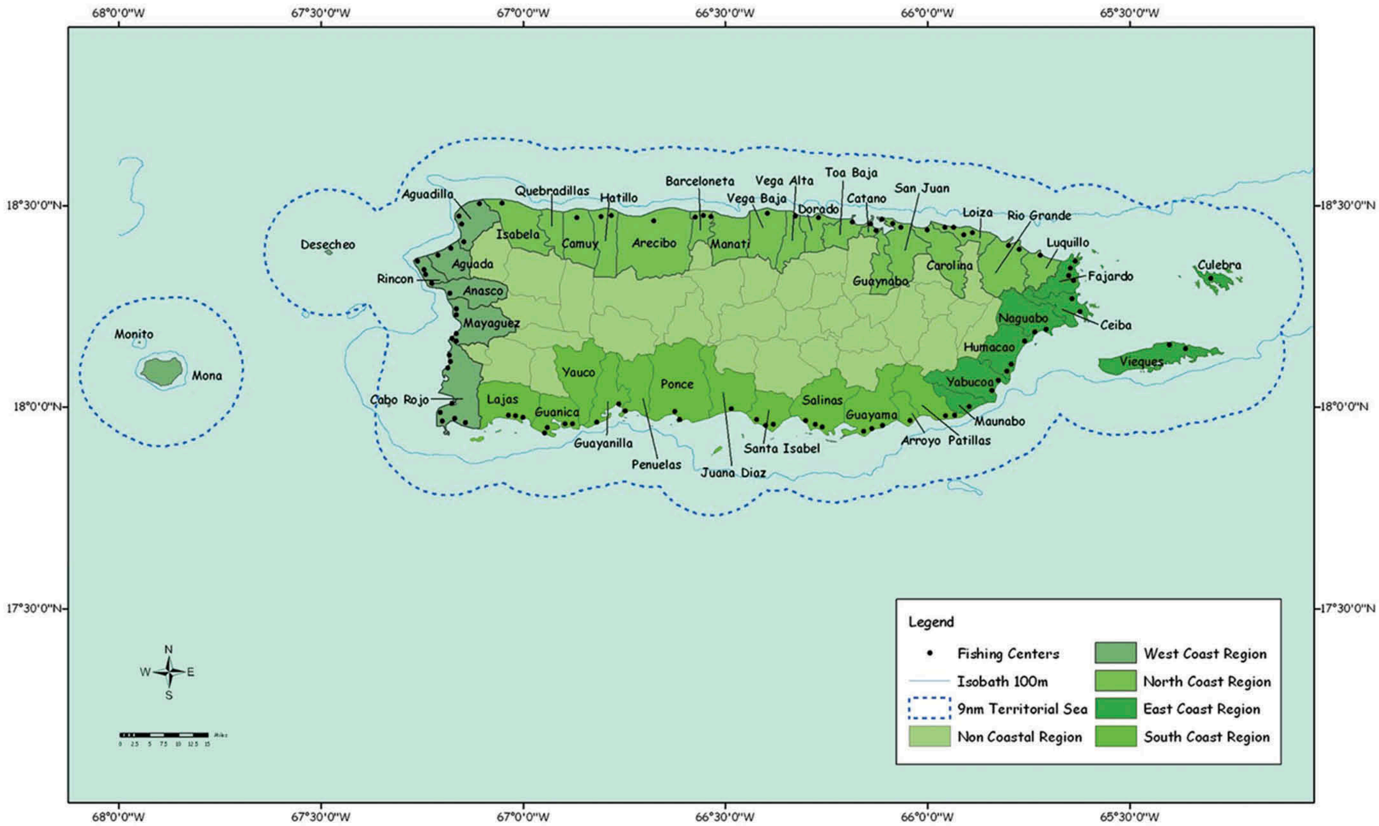

FIGURE 1. Map of coastal regions in the Commonwealth of Puerto Rico, where the trap fishery was studied (nm = nautical miles).

the effects of random shocks to be separated from those of inefficiency, which is not possible with other methods, such as data envelopment analysis (Kumbhakar et al. 2015).

We modeled vessel-level TE per trip by using a Cobb–Douglas SPF model (Kumbhakar and Lovell 2000). The Cobb–Douglas functional form was selected because it is parsimonious in the number of parameters and because we did not encounter convergence problems like those associated with other specifications, such as the translog and Box–Cox transformation.

The empirical model is defined by

$$\log_e(y_i) = \sum_{n}^{j=1} \beta_j \cdot \log_e(x_{ji}) + (\tau \cdot Bait_i) + \sum_{m}^{k=1} \rho_k \cdot Coast_{ki} + (v_i - \mu_i), \tag{1}$$

where y_i is the gross revenue generated by the ith vessel; and the x_{ji} represent the nth inputs (fuel, crew size, and number of traps tended). The SPF model also includes two control variables: *Bait* is a binary variable equal to 1 if the trap is baited and 0 otherwise; and *Coast* is the mth of three coastal-region dummy variables for the north, south, and east coasts, which account for unobserved heterogeneity associated with the fishing grounds. The west coast is the base case. Greek letters represent the parameters to be estimated. Last, $(\nu - \mu)$ is the composed error term ε. The term ν represents a two-sided random error with a normal distribution ($\nu \sim N[0, \sigma_\nu^2]$) that measures stochastic factors beyond the captain's control and underlying technology (e.g., weather, luck, etc.). The term μ is a one-sided, nonnegative component that measures the gap between observed output and maximum feasible output (i.e., the frontier) given the available inputs and underlying technology. Following Jondrow et al. (1982), TE for the ith fishing operation can be estimated as

$$TE_i = \exp(-\mu), \tag{2}$$

where μ is the efficiency term as defined above. The TE for each vessel is calculated using the conditional mean of exp(–μ) given the composed error term of the SPF model (Battese and Coelli 1988). The TE scores are bounded between 0 and 1; a TE score of 1 indicates that fishing vessels are operating on the best-practice frontier defined by the best-performing vessels, whereas TE scores less than 1 indicate that vessels are operating beneath the frontier.

The maximum-likelihood method developed by Battese and Coelli (1995) makes it possible to estimate the determinants of technical inefficiency (TI) in a one-step procedure. Thus, TI can be estimated by incorporating the following expression into the SPF model shown in equation (1),

$$\mu_j = \delta_0 + \sum_{n=1}^{k} \delta_n z_{nj} + \omega_j, \tag{3}$$

where μ_j is technical inefficiency; z_{nj} are variables that affect efficiency; δ_n are unknown parameters to be estimated; and ω_j is an error term. The estimated model also allows us to measure the importance of the captain's managerial skill relative to stochastic shocks. This is done by estimating the parameter λ as the ratio of the SD of the inefficiency term μ to the SD of the stochastic term v (Kumbhakar et al. 2015).

RESULTS

The unadjusted response rate was 51%, which was calculated by dividing the total number of completed interviews by the total number of people contacted (Table 1). Reasons for nonresponse included the inability to locate the fisher (38 fishers), the fisher no longer fished with traps (7 fishers), or the fisher declined to participate in the survey (3 fishers). A Wilcoxon–Mann–Whitney test showed that nonrespondents' annual trap landings (by weight) were statistically lower than those of respondents (P = 0.002). This result, which was derived based on production figures from the original sampling frame, suggests that nonrespondents were less dependent on fishing, which may explain why there were so many unreachable fishers. Disregarding those fishers who either were unreachable or no longer qualified, the effective response rate increased to 94.3%.

Demographic Profile

Most of the trap fishers surveyed were experienced, middle-aged owner–operators with high levels of fishing dependence (Table 2). The average respondent was 57 years old and had 32 years of fishing experience. About 88% of these respondents belonged to age brackets ≥40 years. In contrast, over a decade ago, the average trap fisher was 51 years old and had fished for 30 years, suggesting that recruitment rates continue to decline (Agar et al. 2005). Most new entrants prefer commercial diving because they can target commercially valuable species with minimal investment in craft and gear (Matos-Caraballo and Agar 2011; Agar and Shivlani, in press). The majority of respondents fished year-round on a full-time basis. Part-time fishers fished for income rather than for consumption purposes. Households averaged three family members, including the fisher.

Fishing income was one of the main sources of household income. On average, fishers reported that fishing income made up about 74% of their household income. Eighty percent of the interviewees claimed that fishing income contributed 50% or more to their household income (Table 2). In agreement with other socioeconomic studies of Puerto Rican small-scale fishers, the majority (68%) of trap fishers interviewed refused to disclose their engagement in non-fishing activities, presumably because this information could affect their access to government welfare programs (Agar et al. 2008; Agar and Shivlani, in press). Fishing households regularly complement their fishing income with government transfers and wages from temporary, low-paying employment (Griffith and Valdés-Pizzini 2002; Pérez 2005; Griffith et al. 2007). The remaining 32% of the interviewees reported working in construction, fish sales, boat maintenance, and engine repair, among others.

Capital Investment in Fishing Vessel, Gear, and Equipment

Most of the interviewed fishers had small-sized vessels with limited technology. The average boat was 20 ft long and was outfitted with a 70-hp, gasoline outboard engine (Table 3). Hulls were constructed of fiberglass (70%), wood (18%), or a combination of fiberglass and wood (6%). Fishers estimated that their used vessel and engine(s) were worth $9,704 (range = $700–50,000) and that annual maintenance costs ran about $1,638 (Table 3).

Fishers reported having between 4 and 210 fish and lobster traps in the water, averaging 51 traps. Fish traps were more common than lobster traps because of their versatility (Figure 2). Sixty-six percent of the interviewees said that they fished exclusively with fish traps, 20% fished with both fish and lobster traps, and another 8% used fish traps in combination with other gears, such as lines or scuba. Only 6% of the respondents reported fishing exclusively with lobster traps. Fishers valued their fish and lobster trap endowment with buoys and ropes at $4,182 and estimated that annual maintenance expenses ran about $882. Besides trap fishing, interviewees stated that they also fished with handlines, scuba, trammel nets, vertical lines, trolls, and miscellaneous lines and nets to target a variety of species (Tables 4, 5). Fish traps reportedly lasted about 1.5 years (Table 6).

Cellular phones (84%) and GPS units (48%) were the most commonly owned types of electronic equipment (Table 3). Electronic equipment and safety equipment were valued at $774 and $253, respectively.

Fishing Practices

Fishers reported taking two 7-h trips per week, on average (Table 6). However, they noted spending about 36 h/week on fishing and fishing-related chores, such as vessel and gear maintenance and fish sales. Most operations consisted of a captain and one helper, but larger operations had up to three helpers. Fishers reported several motivations for the fishing trip. Approximately 42% of fishers wanted to maximize landings (or benefits), and another 30% aimed to

TABLE 2. Descriptive statistics for demographic characteristics of trap fishers in Puerto Rico.

Characteristic	Frequency	Percent	Mean	Median	Minimum	Maximum	SE	*n*
Age (years)			56.5	57.0	32.0	86.0	1.6	50
Fishing experience (years)			31.7	32.0	3.0	75.0	2.0	50
Household income derived from fishing (%)			73.7	76.7	10.0	100.0	3.3	50
Number of dependents			3.0	2.0	1.0	7.0	0.2	50
Time spent on fishing activities (h/week)			36.2	36.0	4.0	72.0	1.8	50
Fishing role								
Captain–owner	44	88.0						
Hired captain	2	4.0						
Crew	4	8.0						
Fish year-round	50	100.0						
Full-time	41	82.0						
Waters fished								
Territorial waters	42	85.7						
Federal waters								
Both	7	14.3						
Age distribution								
<30 years								
30–39 years	6	12.0						
40–49 years	11	22.0						
50–59 years	10	20.0						
60–69 years	15	30.0						
≥70 years	8	16.0						
Fishing income distribution								
<25%	5	10.0						
25–49.9%	5	10.0						
50–74.9%	9	18.0						
75–100%	31	62.0						

cover costs. Of the remaining 28%, half had an income or catch target (e.g., land 55 lb of lobster; earn $50 per trip), whereas the other half did not offer a precise objective. Fishing strategies that emphasize cost defraying are closely associated with poor and vulnerable households. They are indicative of the hardships of making ends meet with irregular fishing income since the fishers not only need to finance their next trip (i.e., cover costs) but also likely must meet basic household needs (Agar and Shivlani, in press).

Fish traps are used to catch Caribbean spiny lobsters *Panulirus argus* and various reef fishes, such as Silk Snapper *Lutjanus vivanus*, Mutton Snapper *Lutjanus analis*, Lane Snapper *Lutjanus synagris*, Hogfish *Lachnolaimus maximus*, Yellowtail Snapper *Ocyurus chrysurus*, trunkfishes *Lactophrys* spp., cowfishes *Acanthostracion* spp., White Grunt *Haemulon plumierii*, Red Hind *Epinephelus guttatus*, and parrotfishes *Scarus* spp., among others. Lobster traps mainly catch Caribbean spiny lobsters.

The typical fishing trip starts early in the morning (0630 hours; range = 0400–0700 hours). After steaming to the fishing grounds, the fishers haul, empty, and (sometimes) bait their traps. About 81% of respondents said that they used either one trap (35%) or two traps (45%) per line. About 31% of fishers said that they did not use buoys. The main reason for not using buoys is to reduce the potential for gear theft and/or poaching (Schärer et al. 2004). Fishers reported using fish innards, sardines, squid, and Ballyhoo *Hemiramphus brasiliensis* as bait. Trap tending (soak time) ranged between 1 and 14 d (average = 5 d; Table 6). Schärer et al. (2004) reported that soak times varied depending on factors such as weather, target species (lobsters survive longer in traps than reef fishes), and catch rates. Traps are set at various depths (5–100 fathoms) and habitats (e.g., seagrass beds and hard, sandy and muddy bottoms) depending on weather conditions and species targeted (Schärer et al. 2004). Most (86%) of the trap fishing takes place in Commonwealth waters (<9 nautical miles). After tending their traps, fishers

TABLE 3. Descriptive statistics for fishing vessel, equipment, and gear characteristics of the trap fishery in Puerto Rico (EPIRB = emergency position-indicating radio beacon).

Characteristic	Frequency	Percent	Mean	Median	Minimum	Maximum	SE	*n*
Vessel length (ft)			20.3	19.5	14.0	31.0	0.4	50
Engine propulsion (hp)			70.2	57.0	25.0	300.0	6.8	48
Value of vessel and engine (US$)			9,704.2	5,577.4	700.0	50,000.0	1,148.2	49
Vessel and engine maintenance costs ($/year)			1,638.2	498.8	0	13,000.0	306.9	47
Value of electronic equipment ($)			773.9	199.8	0	4,800.0	140.8	48
Value of safety equipment ($)			252.7	197.8	80.0	800.0	16.3	48
Number of fish and lobster traps			51.2	39.7	4.0	210.0	5.2	46
Total value of fish and lobster traps, including ropes and buoys ($)			4,181.9	2,793.2	750.0	15,000.0	457.7	46
Total maintenance of fish traps and lobster traps ($/year)			881.6	402.4	0	5,000.0	132.0	46
Number of engines								
Single	40	80.0						
Twin	10	20.0						
Engine type								
Inboard	4	8.0						
Outboard	46	92.0						
Hull type								
Fiberglass	35	70.0						
Fiberglass and wood	6	12.0						
Wood	9	18.0						
Crew size (including the captain)								
1 member	2	4.0						
2 members	40	80.0						
3 members	4	8.0						
4 members	4	8.0						
Electronic equipment								
GPS unit	24	48.0						
Winch	13	26.0						
Depth finder	10	20.0						
Fish finder	11	22.0						
Radio	10	20.0						
Cellular phone	42	84.0						
EPIRB	4	8.0						

return to shore in the afternoon or early evening (1330 hours; range = 1000–1700 hours) to market their catch.

Crew Composition, Recruitment, and Turnover

The composition of the crew was mixed, drawing from both kin and non-kin sources. Trap boats were mainly staffed with family members (54%) or a combination of friends and acquaintances (42%). Only 4% of the respondents reported fishing alone. Non-kin crew members were mostly friends rather than acquaintances and were recruited from local or neighboring communities.

Most of the surveyed fishers conceded that crew recruitment was difficult due to the scarcity of qualified and dependable hands. Sixty percent of the respondents said that recruiting crew was "difficult," 4% held that it was "challenging," and an additional 22% stated that it was "easy." The remaining 14% declined to answer, largely because they were unfamiliar with the labor market since they fished mostly with kin. Nonetheless, crew exhibited a high degree of occupational commitment. About 80% of interviewees stated that their operation rarely hired new crew. Another 4% said that they had a new crew member on the majority of their trips, and 2% said that they had a

FIGURE 2. Fisherman emptying an arrowhead fish trap filled with Caribbean spiny lobsters along the east coast of Puerto Rico.

new crew member on every trip. Low turnover rates reinforce the prominence of kinship and affective ties in maintaining a stable workforce.

TABLE 5. Summary of the main species targeted by trap fishers (n = 50) in Puerto Rican coastal waters.

Target species	Frequency	Percent
Deepwater snappers/groupers[a]	22	44.0
Reef fishes[b]	43	86.0
Dolphinfish *Coryphaena hippurus* and Wahoo *Acanthocybium solandri*	10	20.0
Tunas[c]	5	10.0
Sharks[d]	7	14.0
Spiny lobsters *Panulirus* spp.	45	90.0
Conchs *Strombus* spp.	13	26.0
Baitfish[e]	7	14.0
Other species[f]	19	38.0

[a] *Etelis, Lutjanus, Pristipomoides,* and *Epinephelus* spp.
[b] *Balistes, Haemulon, Lachnolaimus, Ocyurus, Lutjanus, Lactophrys, Sparisoma,* and *Mycteroperca* spp.
[c] *Euthynnus, Katsuwonus,* and *Thunnus* spp.
[d] *Galeocerdo* and *Negaprion* spp.
[e] *Harengula, Opisthonema,* and *Hemiramphus* spp.
[f] *Scomberomorus* and *Octopus* spp.

Costs and Earnings

Fishers reported that their operations landed, on average, 57 lb (range = 10–240 lb) of shellfish and finfish per trip, with a dockside value of $290 (range = $50–1,500). After deducting nonlabor running costs (e.g., fuel, bait, ice, etc.), the net returns per trip averaged $233 (range = $22–1,445). The median gross and net returns per trip were estimated at $207 and $153, respectively (Table 7). Fuel expenses roughly accounted for 77% of nonlabor variable costs. Vessels consumed between 2 and 24 gal of fuel per trip, averaging 10.2 gal. Grocery, bait, and ice expenses were responsible for 14, 6, and 2% of the variable costs, respectively. Bait expenses were low because fishers either did not bait their traps (60%) or caught their own bait (29%). Only 11% of the operations purchased bait. Fish innards and skin, sardines, squid, and Ballyhoo were used as bait. Squid and to a lesser extent Ballyhoo and sardines were the main bait species purchased. Similarly, ice expenditures were low because operations either did not ice their catch (52%) or they made their own ice (26%).

TABLE 4. Summary of the main fishing gears used by trap fishers (n = 50) in Puerto Rican coastal waters.

Gears used	Frequency	Percent
Vertical line	6	12.0
Longline	2	4.0
Handline	13	26.0
Shark longline	2	4.0
Rod and reel	4	8.0
Troll	6	12.0
Scuba diving	12	24.0
Skin diving	5	10.0
Fish and lobster traps	50	100.0
Trammel net	9	18.0
Cast net	3	6.0
Beach seine	3	6.0
Gill net	4	8.0
Other		

Remunerative Arrangements

All but one respondent employed lay or share arrangements to compensate capital and labor. This individual respondent paid his crew $0.50 per lb of fish and $1.50 per lb of lobster rather than a share of the net returns (gross revenues minus running costs). Lay arrangements are widely used in fisheries to cope with variable catches and prices since a boat owner's labor obligations are reduced if catches are low. Aside from spreading risk, share arrangements encourage and reward productivity and teamwork (Acheson 1981; Doeringer et al. 1986; Symes and Frangoudes 2001).

Capital and labor income-sharing rules varied significantly. About 70% of the interviewees stated that trap operations did not charge an explicit boat share; however, about one-third of these respondents reported that the captain–owners received a larger share than their crew, partly to compensate for vessel and gear maintenance and investment costs. Twenty percent of the surveyed fishers reported that boat owners charged $10–50 per trip, and another 6% reported that boat owners charged an explicit boat share accounting for about one-third (33–34%) of the net returns (for two-person boats). Respondents stated that trap operations that forwent boat shares tended to be family

TABLE 6. Descriptive statistics for fishing practices used by trap fishers in Puerto Rican coastal waters.

Characteristic	Mean	Median	Minimum	Maximum	SE	*n*
Total crew (including the captain)	2.1	1.6	1.0	4.0	0.1	46
Number of trips (trips/week)	2.3	1.3	0.5	6.0	1.8	46
Trip duration (h/trip)	7.0	6.3	3.0	10.0	0.2	46
Total number of traps	51.2	39.7	4.0	210.0	5.2	46
Number of fish traps	34.2	27.9	0.0	90.0	2.8	46
Number of lobster traps	17.0	0.0	0.0	200.0	4.2	46
Average landings (lb/trip)	57.4	38.6	10.0	240.0	5.3	46
Number of fish traps hauled (hauls/trip)	30.2	24.7	2.0	90.0	2.3	43
Fish trap soak time (d)	5.3	4.3	1.0	14.0	0.3	42
Number of fish traps per line	2.7	1.3	1.0	22.0	0.5	42
Number of fish traps per buoy	1.8	1.2	0.0	12.0	0.2	42
Longevity of fish traps (years)	1.7	1.0	0.5	7.0	0.2	42

owned businesses. They also noted that giving up boat shares was an established practice in many areas.

Sixty percent of the respondents claimed that owner–operators and crew shared net returns equally. Our study found that on average, an owner–operator would earn $138 (range = $14–932) per trip, whereas a crew member would net $89 (range = $7–723) per trip. The median net return per trip was $85 for owner–operators and $60 for crew members. These income figures are higher than those reported by Agar and Shivlani (in press) for the average commercial scuba diving operation. According to that study, the average owner–operator of a diving operation would net about $72 per trip (median = $58; range = $8–235), whereas a crew member would earn almost $61 per trip (median = $50; range = $5–235). During the present study, we found that in the most common trap operation configuration (i.e., a two-person operation), the average owner–operator share was about 56% (range = 33–85%), and the average crew member share was about 41% (range = 15–50%). We estimated that in two-person trap operations, the owner–operator would net $128 per trip on average (median = $86), while the crew member would net $92 per trip (median = $58).

Crew assistance extended beyond the fishing excursion. About 80% of the respondents reported that the crew helped clean, maintain, and repair the boat, engine, and gear. Griffith and Valdés-Pizzini (2002) reported that making and fixing a single trap can take 2–3 h. Most of this supplemental assistance was not directly remunerated. Although this outside assistance probably captures shared cultural values of reciprocal help, it also benefits crew members because it helps to lower outlay costs that otherwise would be deducted from the lay arrangement. Low net returns discourage crew participation. Less than one-fifth of the respondents reported that crew helped cover fishing-associated expenses, such as financing trip-related costs and/or the purchase of craft, engine, and gear.

TABLE 7. Descriptive statistics for the main variable costs and gross and net earnings by trap fishers in coastal waters of Puerto Rico.

Characteristic	Mean	Median	Minimum	Maximum	SE	*n*
Variable costs (US$/trip)						
Fuel expenditures	43.7	37.9	10.0	100.0	2.8	46
Trailer fuel expenses	1.4	0	0	20.0	0.6	46
Ice expenditures	1.3	0	0	10.0	0.3	46
Bait expenditures	3.6	0	0	30.0	0.8	46
Food/grocery expenditures	7.9	7.5	0	30.0	0.8	46
Other expenditures	0.3	0	0	15.0	0.3	46
Total variable costs ($/trip)	56.8	56.5	16.0	119.0	3.4	46
Gross earnings ($/trip)	290.2	207.3	50.0	1,500.0	31.1	45
Net earnings ($/trip)	232.7	152.8	22.0	1,445.0	31.2	45
Fuel consumption (gal/trip)	10.2	9.4	2.0	24.0	0.6	45
Ice usage (lb/trip)	11.8	0	0	100.0	3.1	37
Bait usage (lb/trip)	6.7	0	0	100.0	2.1	40

TABLE 8. Maximum likelihood parameter estimates from the stochastic distance production frontier (SPF) model for the Puerto Rican trap fishery (*$P < 0.10$; **$P < 0.05$; ***$P < 0.01$). The SPF model showed that a 10% increase in fuel consumption, crew size, and number of traps could increase gross revenues by 3.9, 4.1, and 0.9%, respectively. The trap inefficiency (TI) model showed that fishing experience and kinship ties had a positive and statistically significant effect on trap efficiency (TE).

Variable	Coefficient	SD
SPF model		
Constant	4.560***	0.894
Fuel (gal/trip)	0.392***	0.048
Crew (number)	0.412***	0.175
Traps (number)	0.089**	0.038
Bait (dummy)	0.144*	0.080
South coast (dummy)	–0.889***	0.318
North coast (dummy)	–0.587***	0.330
East coast (dummy)	–0.133	0.349
TI model		
Experience (years)	–0.201**	0.088
Buoy trap (number)	–0.036	0.050
Family (dummy)	–0.078*	0.028
Constant	–1.145	1.411
$\lambda = \sigma_\mu/\sigma_v$	1.22***	
Log likelihood	–39.53	
Mean TE	0.64	

Technical Efficiency

We also investigated the TE of the fishery by using an SPF model; Table 8 presents the maximum likelihood parameter estimates. The production model showed that the estimates for fuel consumption, crew size, and number of traps lifted were positive and statistically significant. Because all input variables were logged, parameter estimates measured the responsiveness (partial elasticity) of gross revenues to a change in one input while all other inputs were held constant. These partial elasticities indicated that a 10% increase in fuel consumption, crew size, and number of traps could increase revenues by 3.9, 4.1, and 0.9%, respectively. One plausible explanation for the high elasticities of fuel and labor use is that larger vessels have easier access to productive sites, thereby allowing them to maximize revenues (Oliveira et al. 2010). In addition, setting traps in different fishing grounds may help to spread production risks while minimizing the potential for gear poaching and theft (Abgrall 1974). The parameter estimate on the number of traps per buoy was positive but not statistically significant.

The analysis also uncovered regional differences. Trap operations on the west coast were found to be more productive than those along the south and north coasts. Baiting of the traps was found to increase revenues by 1.4%. The sum of the partial elasticities equaled 0.89, indicating the presence of decreasing returns to scale. Hence, a 10% increase in the use of all inputs would result in an 8.9% increase in gross revenues.

The estimate of λ was equal to 1.22, which indicated that revenue differences across vessels could be explained by skill (or TE) rather than by random shocks (or luck), reinforcing the importance of the captain's managerial skill. The mean TE score was 0.64, indicating the presence of a high degree of TI relative to the best-performing trap operations. This suggests that on average, trap operations could increase their short-term gross revenues by 36% via more efficient use of the existing inputs and technology. Alternatively, trap operations could, on average, hold onto current short-term gross revenues by contracting their input use by 36%. The inefficiency model showed that fishing experience and kinship relationships had positive and statistically significant effects on TE (Table 8). We also found that TE scores were positively correlated with net revenues ($r = 0.78$, $P < 0.001$).

DISCUSSION

The present study revealed a high degree of TI across trap operations. The mean TE score was 64%, suggesting that efficiency improvements could play an important role in improving fisher incomes. Figure 3 shows the distribution of TE scores. Most (82%) of the trap operations realized between 50% and 80% of their gross revenue potential. Close to one-sixth (13.5%) of the operations had TE scores below 49%, and another 4.5% of the operations had TE scores above 80%. Low TE scores have been reported in other fisheries; Kirkley et al. (2002) and Solís et al. (2014) noted that low TE scores are partly driven by the stochastic and multispecies nature of the fishing activity. Based on current reported annual revenues from the Puerto Rican trap fishery, our mean TE score suggests that fishers using fish traps could potentially attain an

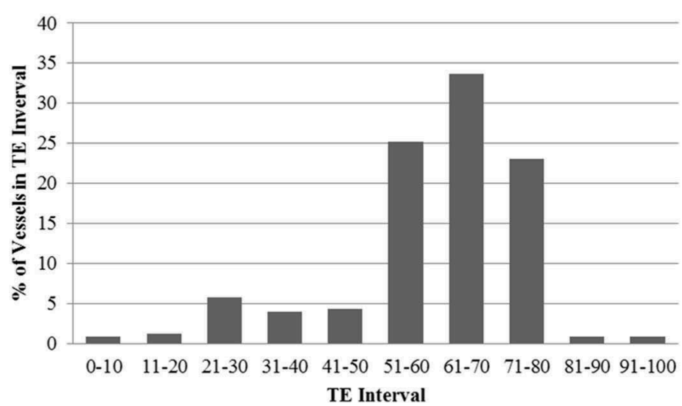

FIGURE 3. Distribution of technical efficiency (TE) scores for trap fishing operations in Puerto Rico. Most operations (82%) realized between 50% and 80% of their full gross revenue potential. The average TE score for the sample was 64%.

additional $186,000 per year without deploying additional fishing effort.

The SPF model showed that the marginal productivity of tending traps was low. A 10% increase in the number of traps lifted per trip would only raise gross revenues by 0.9% on average. Similarly, the use of bait was found to have a modest impact, as it would only raise gross revenues by 1.4% per trip on average.

The TI model showed that fishing experience and kinship ties were main factors that enhanced TE. The significance of fishing experience underscores the importance of fisher skill over fishing technology, which has been also reported in other small-scale fisheries (Oliveira et al. 2016; Pinello et al. 2016). Although fishing experience was expected to improve TE, we were uncertain how kinship relationships among the crew would influence efficiency. Acheson (1981) reported considerable diversity in the composition of crews. Norr and Noor (1974) argued that in fisheries with potential for physical risk, captains may favor recruitment decisions based on skill, teamwork, and compatibility rather than on kinship ties. However, our model showed that kinship ties enhanced TE, probably because operations that rely on familiar bonds (instead of contractual ties) may be better suited to deal with resource and economic fluctuations, labor shortages, and capital accumulation concerns (Acheson 1981). Moreover, van Ginkel (2001) noted that kinship enterprises may be more productive because of their ability to pool and better use scarce economic, social, cultural, and cognitive resources.

Our study results suggest that governmental policies interested in alleviating poverty in fishing communities should consider training and extension programs for fishers to enhance their fishing proficiency. Moreover, the government of Puerto Rico may want to consider policies that support and strengthen family-owned businesses because members of fishing households, particularly the younger members, are increasingly participating in markets for wage labor, which may imperil the medium- to long-term viability of these operations. Further, our results emphasize the importance of socioeconomic data collections, revealing that personal characteristics can play an important role in explaining TI.

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REFERENCES

Abgrall, J. F. 1974. A cost-production analysis of the trap and hand line fishing in Puerto Rico. Doctoral dissertation. University of Rhode Island, Kingston.

Acheson, J. M. 1981. Anthropology of fishing. Annual Review of Anthropology 10:275–316.

Agar, J. J., and M. Shivlani. 2016. Socio-economic study of the hook and line fishery in the Commonwealth of Puerto Rico (2014). NOAA Technical Memorandum NMFS-SEFSC-700.

Agar, J. J., and M. Shivlani. In press. A socio-economic profile of the commercial dive fishery in the Commonwealth of Puerto Rico. Marine Fisheries Review.

Agar, J. J., M. Shivlani, J. R. Waters, M. Valdés-Pizzini, T. Murray, J. Kirkley, and D. Suman. 2005. U.S. Caribbean fish trap fishery costs and earnings study. NOAA Technical Memorandum NMFS-SEFSC-534.

Agar, J. J., J. Waters, M. Valdés-Pizzini, M. Shivlani, T. Murray, J. Kirkley, and D. Suman. 2008. U.S. Caribbean fish trap fishery socioeconomic study. Bulletin of Marine Science 82:315–331.

Akanni, K. A. 2010. Fishing technologies and catch levels among small-scale fishers in Lagos State, Nigeria. North American Journal of Fisheries Management 30:309–315.

Battese, G. E., and T. J. Coelli. 1988. Prediction of technical efficiencies with a generalized frontier production and panel data. Journal of Econometrics 38:387–399.

Battese, G. E., and T. J. Coelli. 1995. A model for technical inefficiency effects in a stochastic frontier production function for panel data. Empirical Economics 20:325–332.

Doeringer, P. B., P. I. Moss, and D. G. Terkla. 1986. Capitalism and kinship: do institutions matter in labor markets? Industrial Labor Relations Review 40:48–60.

Esmaeili, A. 2006. Technical efficiency analysis for the Iranian fishery in the Persian Gulf. ICES Journal of Marine Science 63:1759–1764.

Fousekis, P., and S. Klonaris. 2003. Technical efficiency determinants for fisheries: a study of trammel netters in Greece. Fisheries Research 63:85–95.

Griffith, D. C., and M. Valdés-Pizzini. 2002. Fishers at work, workers at sea: a Puerto Rican journey through labor and refuge. Temple University Press, Philadelphia.

Griffith, D. C., M. Valdés-Pizzini, and C. García-Quijano. 2007. Entangled communities: socio- economic profiles of fishers, their communities, and their responses to marine protected measures in Puerto Rico. NOAA Technical Memorandum NMFS-SEFSC-556.

Jarvis, N. D. 1932. The fisheries of Puerto Rico. U.S. Bureau of Fisheries, Investigational Report 13, Washington, D.C.

Jondrow, J., C. A. K. Lovell, I. S. Materov, and P. Schmidt. 1982. On the estimation of technical inefficiency in the stochastic frontier production function model. Journal of Econometrics 19:233–238.

Kirkley, J., C. Morrison Paul, and D. Squires. 2002. Capacity and capacity utilization in common-pool resource industries: definition, measurement, and a comparison of approaches. Environmental and Resource Economics 22:71–97.

Kumbhakar, S., and K. Lovell. 2000. Stochastic frontier analysis. Cambridge University Press, Cambridge, UK.

Kumbhakar, S. C., H.-J. Wang, and A. P. Horncastle. 2015. A practitioner's guide to stochastic frontier analysis using Stata. Cambridge University Press, New York.

Matos-Caraballo, D., and J. J. Agar. 2011. Census of active fishermen in Puerto Rico (2008). Marine Fisheries Review 73:13–27.

NMFS (National Marine Fisheries Service). 2016. Accumulated Landings System database [online database]. NMFS. Available: http://www.sefsc.noaa.gov/about/statistics.htm. (November 2016).

Norr, J. L., and K. L. Noor. 1974. Environmental and technical factors influencing power in work organizations. Sociology of Work and Occupations 1:219–251.

Oliveira, M., A. Camanho, and M. B. Gaspar. 2010. Technical and economic efficiency of the Portuguese artisanal dredge fleet. ICES Journal of Marine Science 67:1811–1821.

Oliveira, M., A. Camanho, J. B. Walden, and M. B. Gaspar. 2016. Evaluating the influence of skipper skills in the performance of Portuguese artisanal dredge vessels. ICES Journal of Marine Science 73:2721–2728.

Pérez, R. 2005. The state and small-scale fisheries in Puerto Rico. University Press of Florida, Gainesville.

Pinello, D., A. Liontakis, A. Sintori, I. Tzouramani, and K. Polymeros. 2016. Assessing the efficiency of small-scale and bottom trawler vessels in Greece. Sustainability [online serial] 8:681.

Schärer, M. T., M. C. Prada, R. S. Appeldorn, R. Hill, P. Sheridan, and M. Valdés-Pizzini. 2004. The use of fish traps in Puerto Rico: current practice, long-term changes, and fishers' perceptions. Annual Proceedings of the Gulf and Caribbean Fisheries Institute 54:744–756.

Sesabo, J. K., and R. S. J. Tol. 2007. Technical efficiency of small-scale fishing households in Tanzanian coastal villages: an empirical analysis. African Journal of Aquatic Science 32:51–61.

Solís, D., J. Agar, and J. Del Corral. 2015. ITQs and total factor productivity changes: the case of the Gulf of Mexico Red Snapper fishery. Marine Policy 62:347–357.

Solís, D., J. Del Corral, L. Perruso, and J. Agar. 2014. Evaluating the impact of individual fishing quotas (IFQs) on the technical efficiency and composition of the U.S. Gulf of Mexico Red Snapper commercial fishing fleet. Food Policy 46:74–83.

Squires, D., Q. Grafton, F. Alam, and I. H. Omar. 2003. Technical efficiency in the Malaysian gillnet artisanal fishery. Journal of Environment and Development Economics 8:481–504.

Sylvester, J. R., and A. E. Dammann. 1972. Pot fishing in the Virgin Islands. Marine Fisheries Review 34:33–35.

Symes, D., and K. Frangoudes. 2001. The social organization and reproduction of inshore fishingPages 159–175 *in* D. Symes and J. Phillipson, editors. Inshore fisheries management. Kluwer Academic Publishers, Dordrecht, The Netherlands.

van Ginkel, R. 2001. Inshore fishermen: cultural dimensions of a maritime occupation. Pages 177–193 *in* D. Symes and J. Phillipson, editors. Inshore fisheries management. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Whiteleather, R. T. 1971. Puerto Rico fisheries. Pages 134–145 *in* S. Shapiro, editor. Our changing fisheries. National Oceanic and Atmospheric Administration, Washington, D.C.