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Making the most of data-poor fisheries: low cost mapping of small island fisheries to inform policy

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Abstract: Data scarcity in small-scale fisheries hinders the effective management of marine resources. This is particularly true within small island developing states that often have limited capacity for monitoring activities that could inform policy decisions. This study estimates the spatial distribution of fishing activity in the data-poor nearshore reef fisheries of Barbados using low cost interview surveys of fishers combined with a geospatial platform. With data from over 150 fishers in the island's major reef fisheries, the estimated total annual yield ranged from 272.6 to 409.0 mt, with seine fishing accounting for 65% of landings. This estimate is substantially higher than the recorded landings in official databases. Fishing activity is concentrated on the sheltered and heavily populated West Coast of the island. Reef fishing effort decreases markedly during the months associated with the offshore pelagic fishery season, as many fishers switch fisheries during this time and rough sea conditions restrict access to the nearshore windward reefs. The high levels of fishing intensity and low yields per unit of reef area appear to validate anecdotal evidence that the nearshore reefs of Barbados are heavily overexploited. The qualitative nature of interview data and other data gaps hinder the precise estimation of fishing effort and yield, where relative values are likely to be more accurate than absolute values. Nonetheless, the spatially and temporally explicit data generated here demonstrates how simple cost-effective methods can be used to fill important information gaps for marine resource management and spatial planning.

Highlights:

- Estimated landings are over 7 times those recorded in official databases
- Seine fishing for reef pelagics dominates reef fish landings in Barbados
- Barbados' reef production is approximately 1.7-2.6 mt km^{-2} yr^{-1}
- Reef fishing activity is seasonally linked to the offshore pelagic fishery
- Interview data informative for spatial, temporal, and gear-specific management

Keywords: coral reefs, small-scale fisheries, data-poor fisheries, small island developing states, cost-effective methods, Ecosystem Approach to Fisheries

1. Introduction

Heavy fishing pressure is one of the main drivers of coral reef health decline in many small island states [1,2]. In recognition of the impacts of unsustainable fishing on marine ecosystems and the social implications of these impacts, there have been many calls to include ecosystem considerations in fisheries management decisions, giving rise to terms such as an Ecosystem Approach to Fisheries (EAF) [3,4]. Such an approach is important for coral reefs within developing states, where depressed standing stocks of reef fishes pose a significant threat to the livelihood and food security of a wide variety of coastal resource users [5]. One major hindrance to effective reef fisheries management in these countries, however, is the lack of data, where exploitation rates and the spatial and temporal attributes of reef fishing activity are largely unknown [6,7]. The informal nature of most reef fisheries, coupled with limited management resources for monitoring, means that management decisions are made with scarce or inconsistent data [8,9].

In Small Island Developing States (SIDS), the number of suitable fisheries monitoring tools is often limited. More developed nations typically have access to fishers' logbooks (e.g. [10,11]), or to fishing vessel positions recorded either manually by enforcement agencies or by automated vessel monitoring systems (e.g. [12,13]). Fisheries of SIDS, in contrast, generally lack the capacity to carry out such monitoring, especially given that SIDS fisheries are typically small-scale, use unofficial landing sites, and are usually multi-species and multi-gear [8,14]. A variety of interview methods have been devised to elicit fisheries information where formal monitoring data are unavailable (e.g. [15,16]). These low-cost methods can be used to derive spatially-explicit data that can be analysed in geographic information systems (GIS) [17,18]. These data collection activities can also be an opportunity for fisheries managers to interact with and engage fishers in monitoring and management [15]. Although these methods can be time-consuming and reliant on voluntarily supplied information, they can be particularly useful within small island contexts. The limited size of many SIDS communities enables a relatively high proportion of the fisher population to be interviewed, which is likely to improve accuracy in representing fleet-wide fishing activity [19,20].

In Barbados, a small island developing state where the reef fisheries are open access and considered of minor economic importance (compared with the offshore pelagic fishery), reef fishing remains mostly unregulated and unmonitored and thus data-poor [7]. In addition to other coral reef pressures (e.g. pollution, severe bleaching events [21,22]), it is generally acknowledged the reef fish resource is heavily overfished [7,23]. Yet, no empirical evidence exists that would allow for the determination of the true status of the reef fisheries and the relative intensity of fishing activity across different reef areas or times of year [24]. The majority of the national fisheries data focuses on the more lucrative offshore pelagic fisheries [25], with only a few select studies in the grey literature reporting on individual reef fisheries within the last decade. The most notable of these studies include Schuhmann et al. [26], who provided a detailed description of the island's nearshore trap fishery, and Maraj et al. [27] and Simpson et al. [28] who recently reported on fishing activity within the nearshore seine and spear fisheries respectively. Although these and other site-level studies exist (e.g. [29]) there has not been any effort to provide a comprehensive assessment of reef fishing activity in Barbados, particularly how it varies across space and time and the relative importance of the different gear types and reefs to overall landings. Without these data, the levels of exploitation on Barbados' reefs remain unknown and managers lack the necessary information to develop management policies that promote sustainable use. Such information would be particularly timely, as the government of Barbados is currently investing heavily in a Coastal Risk Assessment and Management Programme (CRMP 2012–2018 [30]) with attention being given to the rehabilitation of nearshore reefs. As such, data on the spatial and temporal distribution of reef fishing activity would complement water quality and other oceanographic data being collected by the CRMP. In Barbados and elsewhere, such data would help researchers, coral reef stakeholders and management practitioners to: 1) identify economically important fishing areas; 2) identify potentially overexploited reef areas in need of immediate attention; 3) help explain observed variation in reef fish communities and reef health across sites; 4) help assess the potential social and ecological implications of various management options (e.g. marine zoning, temporal closures, gear restrictions, etc.) and; 5) engage in participatory spatial planning exercises where maps can provide visual aids for collaborative decision-making and trade-off analyses regarding competing uses of marine spaces [15,31].

This research applies a transferable, low-cost approach to address some of the major knowledge gaps within the Barbados nearshore reef fisheries using spatially explicit data provided by resource users. Quantitative and qualitative interview data on catch, effort and fishing ranges were compiled from interviews with over 150 fishers targeting reef-associated species with one or more of the main reef fishing gears: seine nets, traps (pots), spearguns and handlines, and used to estimate the spatial distribution of fishing effort and yield on the nearshore reefs of Barbados.

1.1. Barbados' reef fisheries

The Barbados Fisheries Division records shallow reef fish landings under several aggregate categories [32] making it difficult to accurately quantify landings. The "demersal reef fish" category represents < 1% of total annual landings, with flyingfish and large pelagic species accounting for around 95% (2010 values), and AOV ('any other variety', which includes reef and non-reef species) accounting for approximately 3%. Approximately half of the island's registered fishing vessels are 'moses', small open vessels (typically 4.6–5.8 m in length with 15–40 hp outboard engines), used primarily in the reef and nearshore fisheries [32,33]. The main species landed by the reef fisheries include parrotfishes (Scaridae), surgeonfishes (Acanthuridae), and big-eye scad (Selar crumenophthalmus). See Supplemental Table 1 for descriptions of the four major types of fishing activities (line, seine, spear, and trap fishing) and target species within Barbados reef fisheries.

The reef fishery in Barbados, although poorly monitored and considered a minor fishery, is important to coastal livelihoods, food security and the country's economy [24]. For example, reef fisheries represent an important social safety net for coastal communities, acting as a secondary income source for seasonal pelagic fishers and those working in the seasonal tourism sector, and providing employment for older fishers when they 'retire' into reef fishing after years in the more strenuous offshore fisheries [34]. Efforts to quantify the economic value and impact of reef fisheries have resulted in highly variable estimates. Mahon et al. [35] estimated the national gross value of reef fish landings at US$44,657 per year with an additional US$31,579 in value from processing and preparation (cooking). Other reef-associated species such as reef pelagics (namely Selar crumenophthalmus) and lobster (Panulirus argus) were valued at US$50,749 and US$14,638 respectively (including post-harvest value). These estimates are based on official landings data which exclude an unknown (but likely significant) quantity of reef fish landings, given that monitoring occurs only at a few official sites and not at the many unofficial landing sites used by this fishery [24,25]. On the other hand, using fisher interview data, Schuhmann et al. [26] estimated the gross revenues from trap fishing alone to be between US$ 0.39 and 0.75 million per year. More recent research estimated that the annual net revenue from reef fishing in select fishing communities ranged from US$46,285 to US$84,146 per community [36].

2. Methods

2.1. Data sources

In this study the researchers compiled existing data on Barbados' reef fishery to create a spatially explicit dataset of the island's commercial reef fishery. Between 2009 and 2013, over 150 small-scale commercial fishers were interviewed in four separate studies focusing on reef fishing in Barbados (Table 1). Three of the four studies focused on a specific reef fishery: trap fishing [26]; seine fishing [27]; and spear fishing [28], whilst the fourth study [29] focused on all reef fishing activity at three key reef fishing sites (Six Men's, Holetown, Pile Bay; Fig. 2) and their neighbouring communities on the West Coast of the island [36]. All studies shared at least one researcher, allowing for information and database sharing and preventing duplication of interview data. The following sections give a brief overview of the scoping and interview methods used to collect the fisheries data, and the major steps to compile these data to generate the fishing activity maps (see [26–28,36] for data collection methods). These include: 1) scoping; 2) fisher interviews; 3) annual yield estimation; 4) creation of fishing area polygons; and 5) data treatment and validation.

Table 1. Description of studies from which the fisher interview data were sourced

Fishing activity	Study	Geographic scope	Major study objective
Line, Seine, Spear, Trap	Gill [29]	Centred on three major fishing and/or tourism communities (Six Men's, Holetown, Pile Bay; Figure 2) but covers fishing activity along the N, W and SW coasts of the island	Estimate the economic value of reef fish to reef fisheries in and around three fishing and/or tourism dependent communities
Seine	Maraj et al. [27]	Island-wide	Provide a detailed description of the island's seine fishing capacity, fisher demographics, fishing practices and approximate yield
Spear	Simpson et al. [28]	Island-wide	Fill knowledge gaps concerning the islands' spear fishery, particularly its importance in contributing to livelihoods, the distribution of fishing effort and the total annual landings of the spear fishery
Trap	Schuhmann et al. [26]	Island-wide	Estimate the economic contributions of the Barbados trap fisheries sector to the national economy

2.2. Scoping

Prior to conducting interviews, a scoping exercise was undertaken to provide contextual information and identify optimal locations for sampling specific fisher populations. Fisheries officers and respected members of local communities played an important role in providing information on the number and location of the major fish landing sites, major types of fishing, estimated number of fishers within the communities, popular fishing grounds, and fishing seasonality. Primary and secondary data and reports were also reviewed during this phase.

2.3. Fisher interviews

Only fishers who were actively engaged in fishing of reef-associated species (demersal and pelagic reef fish and invertebrates) within the last 12 months were interviewed. During the interview process, additional names of fishers were collected until no new names were encountered (i.e. snowball sampling [37]). Although fishers who only fish occasionally may be missed using this approach, snowball sampling is ideally suited to identifying active fishers (who are the target group for this study) known in the community for their fishing activity. Face to face interviews were conducted with reef fishers across all studies using a standard subset of questions. Sampling was stratified by community and/or gear type. In each interview, fishers were asked to provide estimates of their trip frequency each week or month, average trip catch, and geographic fishing ranges (Table 2). Many of the interview questions and tools were adapted from the socio-economic monitoring manual (SocMon) [38,39]. Data on fishing operations (e.g. target species, hours fished, costs and revenue, etc.) and demographic information were also collected. Fishers identified their fishing ranges on provided maps or by reporting the alongshore boundaries using well recognized coastal landmarks or communities.

Table 2. Required input data to derive estimates of fishing effort and yield.

	Data needed	Description	Instrument/source
Interview data	Fishing activity/gear	Type of fishing gears used by fisher or vessel	Fisher surveys (e.g. "What types of gear do you use/fishing do you do?")
	Effort	Number of trips per week or month, disaggregated by fishing activity/gear	Fisher surveys: seasonal calendars, (e.g. "How many times per week do you do line fishing in each month of the year?"). In Maraj et al. [27], number of observed seasonal trips were also recorded.
	Catch	Average catch per trip for each type of fishing activity/gear	Fisher surveys: average catch or midpoint of a range of values (e.g. "What is your average catch per trip for spearfishing?"; "How much do you get on a good/bad seine fishing day?"). In Maraj et al. [27] and Simpson et al. [28], samples of catch weight were also recorded.
	Fishing area	Area used by fisher or vessel for each type of fishing activity/gear	Maps, fisher survey questions on outer boundaries of fishing ranges (e.g. "Where do you go when trap fishing?")
Secondary data	Total number of fishers	Estimates of the total number of fishers engaged in each fishing activity/gear	National fisher database verified by key informants
	Total fishable area	Map of fisheries habitats (e.g. coral reefs and associated habitats)	Benthic habitat map [40]

Based on the estimated total number of fishers identified in the scoping exercises, each study interviewed between 50% and 100% of the target fisher population within each site and/or fishery. The authors drew upon the 2007 national list of registered fishers from the Barbados Fisheries Division and key informants to derive estimates of the total number of fishers involved in the various reef fisheries on the island. With these estimates, a scale/multiplication factor was applied to the combined yield and effort values to account for the activity of fishers that were not interviewed.

2.4. Estimating annual yield

Using the data from the four studies, the total annual yield (mt yr−1) was estimated using: 1) reported catch per trip (as weight); 2) reported number of fishing trips per year and; 3) the number of interviewed (and estimated number of un-interviewed) fishers (Eq. (1)). Here, catch represents the total yield of reef-associated species such as demersal and pelagic reef fish, and invertebrates such as lobster, conch, octopus and crabs (Supplemental Table 1).

Data from boat owners and crew members sharing a vessel and gear (e.g. seine net, traps) were pooled to provide a single record of fishing yield and area for each type of fishing on each vessel (or for each individual fisher in the case of those not using a boat). This resulted in 100 unique spatially defined fishing records. Preference was given to the information provided by the boat owners (who were almost always the boat captains) as some crew members fished on multiple vessels. If an owner was interviewed in more than one study, the mean of their responses was used (n = 2 of 100).

2.5. Creating fishing area polygons

The researchers used Esri ArcGIS 10.2.2 software to create 100 individual polygons (one for each fishing record) representing the fishing ranges reported by each commercial reef fisher for his/her individual or vessel's fishing activity. Single polygons were used to describe fishing activity of multiple individuals that fished on the same vessel. If vessels/fishers carried out more than one type of fishing activity, separate polygons were drawn. The outer edge of the offshore reefs was used as the seaward boundary of the fishing ranges, since all reef fishing activities occur between there and the shore. As this study focuses on nearshore (shallow reef < 50 m depth) fishing activity, data on the island's deep-slope snapper fishery were excluded. Reef habitats were identified using a georeferenced benthic habitat map of the island [40]. Under the assumption that fishers are compliant with national regulations, the fishing range polygons were clipped to exclude areas that overlapped with the island's only marine reserve (Folkestone Marine Reserve) and other areas where fishing is not allowed (e.g. inside the island's main port) (Fig. 2).

For each polygon (i), the annual fishing intensity (yield per unit area) was calculated by dividing the estimated annual yield (mt yr−1) by the area fished (Equation 1). Fishing intensity was assumed to be evenly distributed across the polygon area as in [19,41,42]. A fine-scale gridded raster (cell size 10 × 10 m2) was then overlaid onto the fishing polygons (i), where each grid cell (j) assumed the fishing intensity value from the polygon (or in cases where polygons overlapped, the sum of each polygon value). These rasterization and summation steps were performed using the 'rasterize' function in the raster package of R statistical software [43]. Cell size (10 × 10 m2) appeared to be the appropriate balance between computational load and map quality.

Equation 1. Fishing intensity (mt km^{-2} yr^{-1}) for all fishing activities (i=1…n) utilizing the reef area within a given grid cell (j).

$$Fishing\ intensity\ (mt\ km^{-2}\ yr^{-1})_j = \sum_{i=1}^{n} \left(\frac{\sum(trips\ yr^{-1}) \times trip\ catch\ (mt)}{Total\ area\ fished\ (km^2)} \times \frac{estimated\ total\ no.fishers}{no.fishers\ interviewed} \right)_{ij}$$

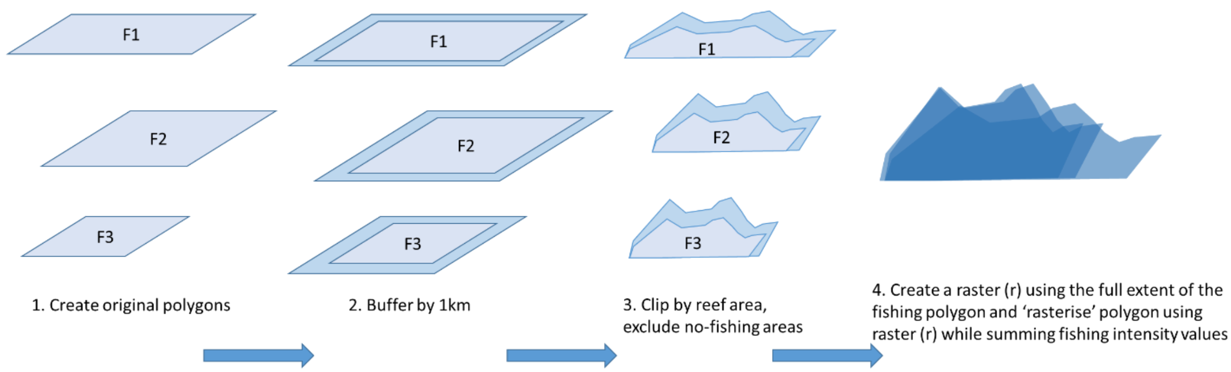

Figure 1. Workflow for creating the fishing intensity maps: 1) create polygons to represent fishing area; (2) buffer the clipped regions to account for imprecise boundaries; 3) clip the buffered fishing ranges to the reef area (4) create a raster (0.01 km^2 (10m x 10 m) cells in this study) and sum yield values in each cell.

2.6. Data treatment and validation

The reported fisheries data were assessed for both quality and gaps. In cases where catch or effort data were not available for a fisher/vessel, estimates were derived using other related information supplied during the interview (e.g. general seasonality of fishing, "good days" and "bad days" catch[1]). Otherwise, the researchers imputed mean or trimmed mean (average of the middle 80% of the data to remove extreme outliers) values for catch (n = 17 of 100 records) and effort (n = 9 of 100), based on other fishers using the same gear and/or proximate landing sites.

Across the studies, it was noted that fishers were susceptible to overestimating their fishing effort. Inflated estimates of effort may be due to recall bias, rounding, or extrapolation to other similar activities (e.g. responding to a question about trap fishing using frequencies for other types of fishing) [44]. Further, survey questions were constructed in a way that prompted fishers to respond using rule-based estimates of effort (e.g. "I fish 5 days per week"). Subsequently multiplying such heuristics to a larger time frame to construct estimates of annual catch or effort produces estimates that are likely biased upwards due to the omission of exceptions to the rule (e.g. days missed due to mechanical problems, poor ocean conditions or poor fisher health) and rule shifts during the time frame of the question (e.g. seasonal changes in catch or effort [44,45]). Even though the researchers in each study attempted to mitigate this bias by top-coding verbatim responses such as "I fish every day" to five days per week, the possibility of bias remains. Unfortunately, the literature does not provide guidance with regard to the magnitude of such bias in the context of commercial reef fishing. However, using interview and observation data, Maraj et al. [27] noted that seine fishers would overestimate both their catch and effort by almost two times. Therefore, annual yield across all reef fisheries are estimated and reported at 50–75% of the total calculated[2], which is a plausible range that accounts for expected overestimation.

Fishers often gave imprecise boundaries for their fishing areas (e.g. the names of communities or bays with no established demarcations). Others gave one landmark where most of their fishing centres around. To account for this imprecision, polygons were buffered by 1 km beyond the stated landmarks (Fig. 1).

[1] Gill [29] used linear models to predict average catch from estimates of 'good' or 'bad' day's catch.
[2] Maps show the original annual yield estimates as reported by the fishers while the reduced estimates are reported elsewhere in the Results (Section 3.3).

Further, where there were discrepancies in the fishing ranges between fishers from the same vessel, the wider range was used. The wider range allows for the inclusion of all areas mentioned by fishers and produces a more conservative estimate of fishing intensity (yield per unit area) given that it includes a larger area. This is a preferred trade-off given the tendency of fishers to over-estimate their fishing activity [27].

The fisheries data and maps were also validated by: 1) comparing yield estimates to other local and regional fisheries assessments; and 2) using feedback on the results from local researchers and fisheries and coastal zone management agency representatives.

3. Results

3.1. Spatial and temporal distribution

Based on the values reported by the commercial fishers (and accounting for the number of un-interviewed fishers), commercial reef fishing intensity around the island ranged from 0.29 to 7.22 mt km^{-2} yr^{-1}. The majority of fishing effort was concentrated on the populated west and southwest coasts, particularly off the Six Men's and Pile Bay fishing communities (Fig. 2). Most of the fishing activity on the east coast was around Consett Bay, where offshore reefs in that area attenuate the incoming wave energy and allow nearshore fishing and anchoring. Reef fishing yield in the months associated with the pelagic fishing "off season" (June to November) was on average 2.4 times higher than that of the pelagic fishing months (December to May) (Fig. 3), when many reef fishers engage in the offshore pelagic fishery [7]. The pelagic fishing months also coincide with high trade winds and associated rough sea conditions which preclude nearshore fishing activity on the north, east, and southeast coasts.

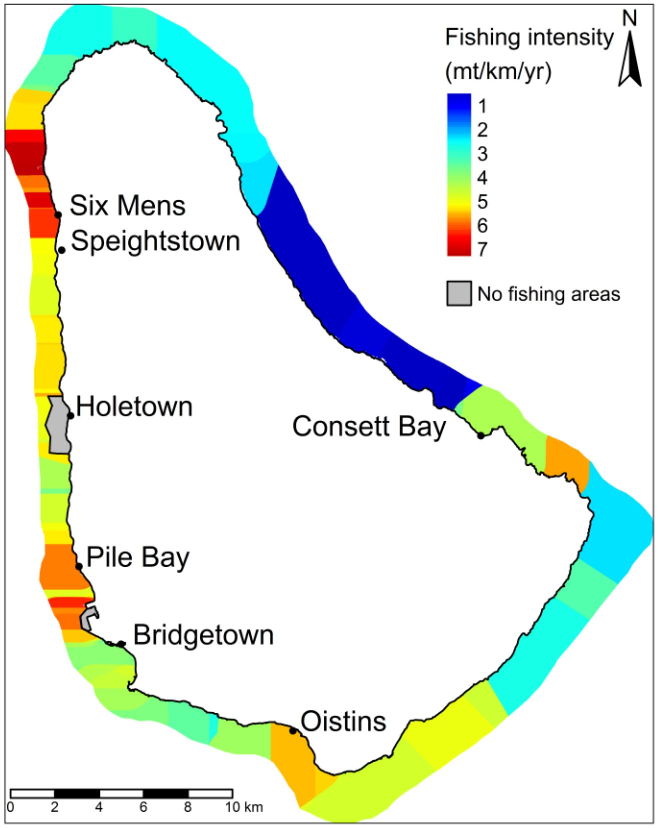

Figure 2. Variability in annual commercial fishing intensity (mt km^{-2}yr^{-1}) for reef-associated species on the nearshore shallow shelf in Barbados.

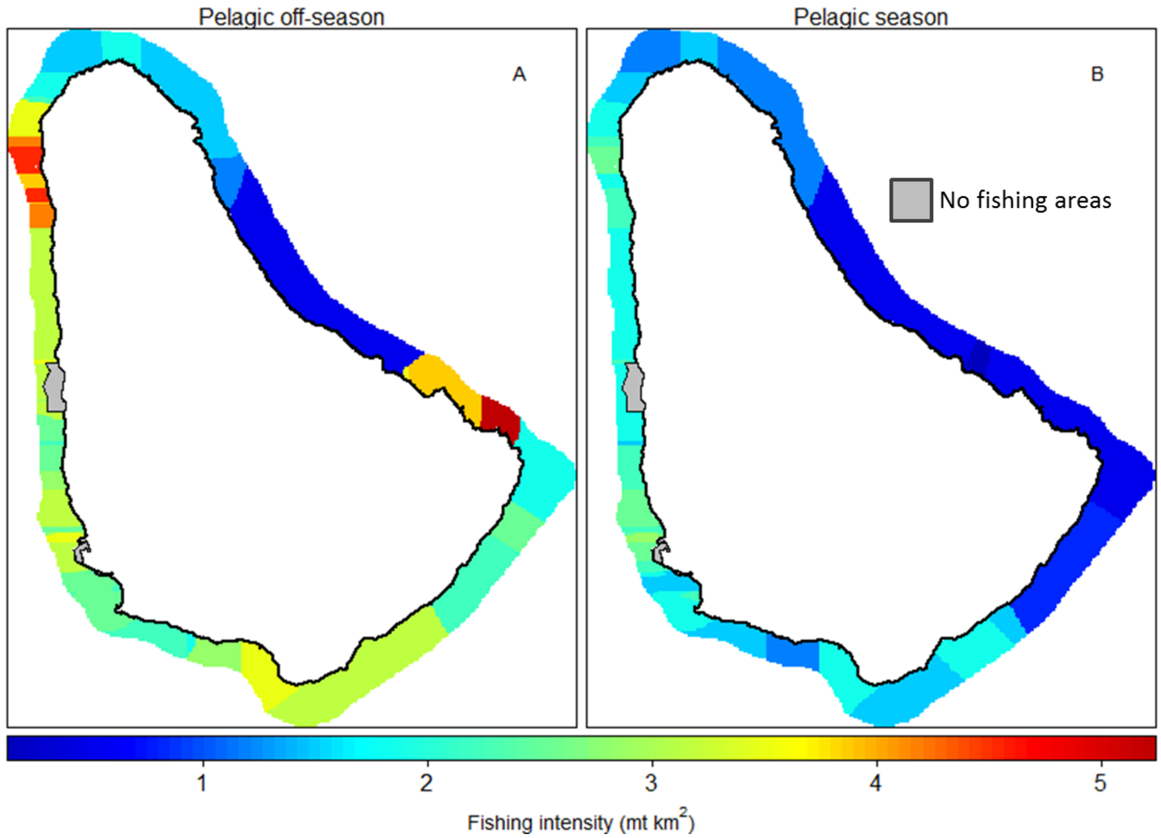

Figure 3. Spatial variation in reef fishing intensity (mt km^{-2}) on Barbados' nearshore shallow shelf during the (A) pelagic fishing 'off-season' (Jun-Nov) and the (B) pelagic fishing season (Dec-May).

3.2. Fishing activity by gear

Fishing effort and yield varied considerably by gear type (Table 3). Although seine fishers reported the largest catch per trip, there were only six identified vessels at the time of sampling, and based on observations by Maraj et al. [27], approximately 90% of landings were reef pelagic species (namely Selar crumenophthalmus). On average, seine fishers and spear fishers had the widest fishing ranges, and while seine fishers concentrate on the west and south coasts, spear fishers were more widely distributed around the island (Fig. 3). Trap fishers reported the smallest fishing range of all gears, with gear theft mentioned as one reason why they choose to fish close to the landing sites.

Table 3 Summary of reported and estimated commercial fishing activity by fishing activity/gear. Values here represent the mean values from the vessel-level (or shore fisher) data by fishing activity that were used in the spatial analysis. Reported and estimated annual fishing intensity represent the total annual yield per km^2 of the interviewed fishers (reported) and of all fishers island-wide (estimated) respectively.

Fishing activity	n	% of estimated total no. of fishers	Reported values (mean)				Estimated fishing intensity (mt km^{-2})		
			Catch per trip (kg)	Trips per year	Approx. fishing area (km^2)	Annual fishing intensity (mt km^{-2})	Annual	Pelagic off-season	Pelagic season
Line fishing	13	74.9*	7.6	126.2	16.24	0.08	0.10	0.06	0.04
Seine fishing	6	100.0	604.7	85.6	48.36	1.38	1.38	1.19	0.19
Spear fishing	39	69.0	13.0	157.2	39.87	0.08	0.11	0.07	0.05
Trap fishing	42	84.0	16.7	65.4	9.34	0.18	0.21	0.13	0.08

* Total number of line fishers island-wide not known. Estimate based on number of un-interviewed fishers in and around communities surveyed in [29].

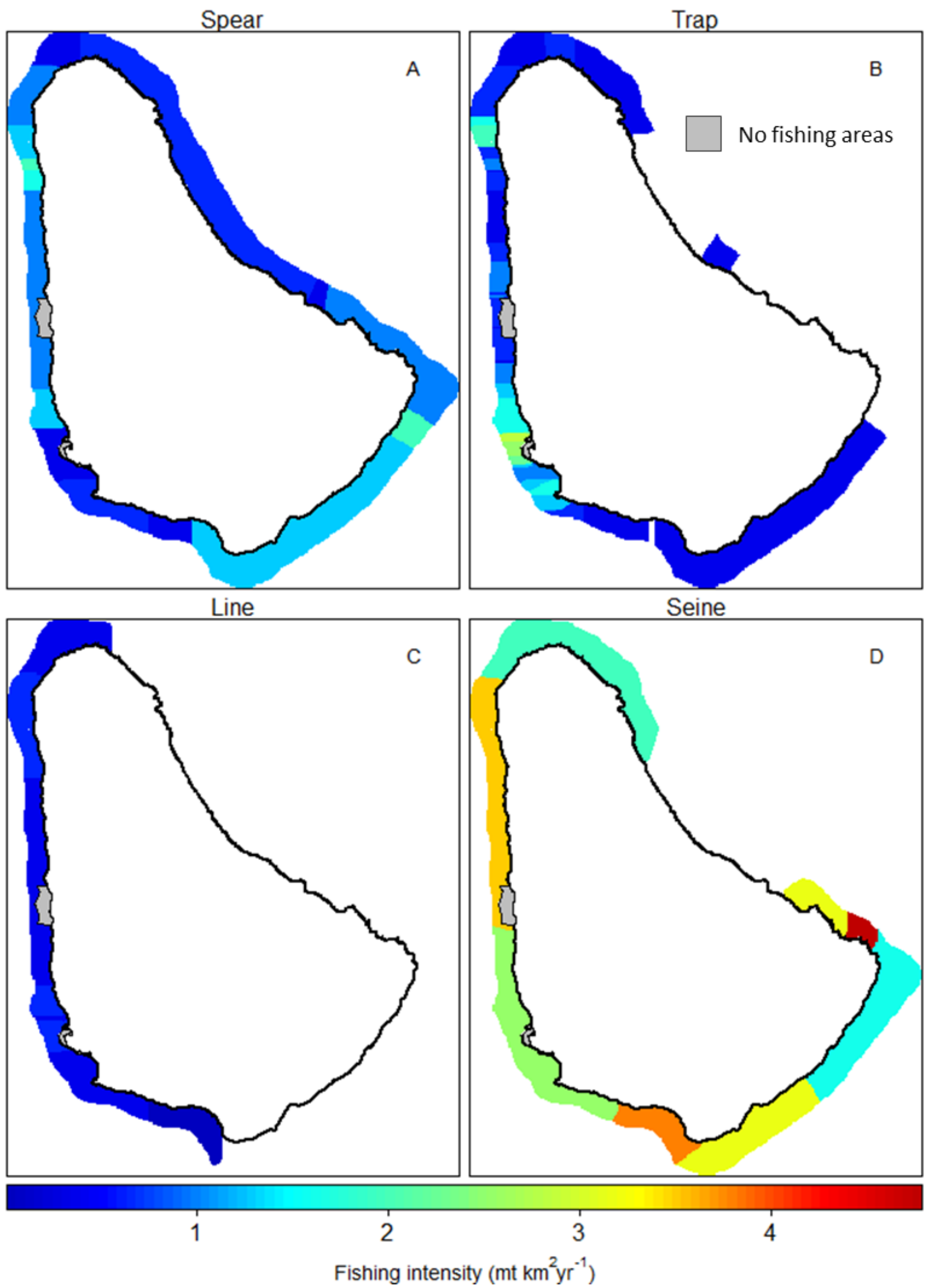

Figure 4 Spatial variation in fishing intensity (mt km^{-2} yr^{-1}) from (A) spear fishing, (B) trap fishing, (C) line fishing, and (D) seine fishing.

3.3. Total annual yield and reef productivity

Based on the reported average trip catch, the number of trips per year, and the estimated number of un-interviewed fishers, the total estimated yield from all commercial reef fishing activity is 545.3 mt yr−1

(Table 4). Given that the reported values are likely to be overestimates (see Section 2.6), a more probable estimate of commercial reef fishing yield may lie between 272.6 and 409.0 mt yr−1. Based on this range, and given that there is approximately 156 km2 of coral reef associated habitat supporting these nearshore fisheries, reef productivity in Barbados could equate to approximately 1.7–2.6 mt km−2 yr−1 for all reef-associated species. Pelagic reef fish account for a large portion of the seine fishery landings (approximately 157.6–236.5 mt yr−1) which also translates into 57.8% of overall landings. When these are excluded from the total estimated reef fish landings, reef productivity is approximately 0.74–1.10 mt km−2 yr−1.

Seine fishing and spear fishing landings represent the largest shares of overall landings, at approximately 176.4–264.6 mt yr−1 and 61.0–91.5 mt yr−1 respectively (Table 4). High values for these two fisheries appear to be due to large trip catch (seine) and high trip frequency (spear; Table 3). Lower annual landings were observed for trap (27.4–41.1 mt yr−1) and line fishing (7.9–11.8 mt yr−1). Trap fishers have the lowest trip frequency, hauling traps on average, just over once per week (Table 3). Line fishers have the lowest landings, partly due to lower catch rates, and possibly also due to limited sampling coverage.

Table 4. Estimated annual landings for the four major reef fisheries in Barbados. Calculated totals represent the island-wide estimates using reported catch and effort values and accounting for un-interviewed fishers. These values were reduced by 25%-50% to account for potential overestimation in the reported values.

Fishing activity	Estimated total landings (mt yr^{-1})		Proportion of total
	Calculated total	25%-50% reduction	
Line fishing	15.8	7.9-11.8	0.03
Seine fishing	352.8	176.4-264.6	0.65
Spear fishing	122.0	61.0-91.5	0.22
Trap fishing	54.8	27.4-41.1	0.10
Total	545.3	272.6-409.0	1

4. Discussion

The management importance of spatially and temporally explicit data on small-scale fishing activity has been repeatedly emphasized in the literature (e.g. [41,46,47]). These data are a prerequisite for understanding the behavioural dynamics of fishers, the relative importance of various locations and seasons to the fishery, variability in impacts on marine ecosystems, and assessing the potential effects and effectiveness of management interventions [19,46]. Unfortunately, in developing countries these data are usually scarce due to lack of adequately trained staff, financial support, and permanent evaluation programs [48]. This study presents a simple, yet effective way to rapidly assess the spatial and temporal variability in fishing activity within a small-scale fishery. The fisher interview data were subsequently combined with available biophysical data on the location of reefs surrounding the island to estimate and visualise the relative intensity of fishing pressure on reef resources.

4.1. Methods and limitations

As with other approaches, interview methods have their limitations: reliance on fisher participation, memory recall, distrust between researchers and fishers, reticence to provide accurate information because of the competitive advantages of maintaining secrecy about fishing grounds, and possible consultation fatigue [16,49–51]. Resulting estimates are also heavily influenced by sample coverage [42].

It is recognized that the sampling effort in this study was slightly weighted towards the west coast, since only the Gill [29] study interviewed line fishers and that study was restricted to the communities of Six Men's, Holetown and Pile Bay (and their environs; Table 1). It is also expected that the precision of the fishing polygons will vary from fisher to fisher. Nonetheless, the researchers believe that despite these data limitations (and possible uncertainty surrounding the absolute yield values), the relative distribution of fisheries yield (by location, season and gear) is appropriately represented here. For example, even though sampling for line fishers occurred only on the west coast, line fishing (which usually involves demersal fishing from a stationary vessel) is highly unfavourable on the exposed eastern coast, and the current sample accounts for some line fishing activity on the north and southwest coasts. Further, the weighting of sampling effort towards the west and south coasts corresponds to the general distribution of fishing activity on the island [24], and Six Men's, Holetown and Pile Bay were major reef fishing sites identified by key informants [36]. With regard to the accuracy of interview data, other studies have observed strong congruency between spatial and economic data from fisher interviews and other sources with regard to fishing activity, gross earnings, and species occurrence [19,42,52]. In this study, trip catch rates reported in the official landings data and the interview data appear to be comparable for some fisheries (e.g. trap fishing catch)[3].

In Barbados, 'subsistence fishing' does not occur separately from the small-scale commercial fishery and as such any 'subsistence landings' are already accounted for in the estimates obtained in this study. However, some recreational fisheries (i.e. spearfishing and shore-based handline fishing) include subsistence landings and could represent an important share of the total annual reef fish yield [28]. These remain unaccounted for in this study, as well as in official landings data.

Overall, the comprehensiveness and accuracy of this assessment of Barbados' reef fisheries could be improved by: 1) an island wide assessment targeting line fishers (recreational and commercial); 2) an island wide assessment of other recreational fisheries; 3) validation exercises with groups of fishers that are representative of the different types of fishing activities (including recreational fishers) and communities and; 4) validating the fisher responses with observational recordings on fishing areas, trip frequency, and landings as in [27].

4.2. Management implications and future research

Even when accounting for the overestimation bias, the lower bound estimate of demersal reef fisheries yield (omitting the reef-associated pelagics from seine fishing) was approximately 7.4 times the amount recorded in official landings (annual average of 15.6 mt over the period 1997–2006 [26]). Also, reef-associated pelagic fish yield was approximately 10.6 times the amount recorded in official landings (annual average of 14.9 mt over 1997–2006 [25]). Nonetheless, the range of 272.6–409.0 mt yr^{-1} reported here closely aligns with the Sea Around Us Project's 2011 reconstructed estimates of 413.2 mt yr^{-1} for all reef-associated species in Barbados[4][53,54]. As reported trip catch rates for some fisheries appear to be comparable to the official landings data3, the major differences in annual yield are likely due to differences in fishing effort and the recorded number of fishers. Both these values are known to be either underreported or erroneous within the official landings database [25,26]. These estimates suggest that

[3] Catch per trip as reported by interviewed trap fishers in this study (16.7 kg; Table 3) was approximately the same as the ten-year average catch recorded in the official Caribbean Fisheries Information System (CARIFIS) dataset for 1997-2006 (16 kg) for trap fishers [26].

[4] Includes lobsters, crabs and relevant small and medium reef associated and pelagic fish species.

reef fishing activity in Barbados is vastly underreported (as corroborated by [7,25,55]) and thus uninformative for management and policy.

Our data suggest that shallow shelf reef productivity for Barbados lies within the range of values reported elsewhere in the insular Caribbean (0.5–4.1 mt km^{-2} yr^{-1}; see [56] for a review). However, based on the spatial data compiled here, this study identifies select reef areas where fishing intensity is well beyond these levels and potentially overfished. For example, using Munro and Thompson's [57] estimate of a maximum sustainable yield (MSY) from the Jamaican reef fishery of 4.1 mt km^{-2} yr^{-1} (or 2.2 mt km^{-2} yr^{-1} as calculated in a subsequent reanalysis [58]), fishing intensity in Barbados exceeds 4.1 mt km^{-2} yr^{-1} in 47% of the reef area (or 85% of the lower reanalysis estimate), namely along the northwest and southwest coasts (Fig. 2). Neilson et al. [56] suggested a more realistic range for fisheries productivity on Caribbean coralline shelves was between 1.7 and 2.3 km^{-2} yr^{-1}. As such our results demonstrate that management of fishing activity in these intensively fished areas should be a high priority to prevent the continuing decline and ultimate collapse of the reef fish resource.

These data also reveal the comparative spatial and seasonal contributions of the different reef fisheries/gears to the overall reef fish yield. Such information is clearly useful for informing decisions on spatial, temporal, and gear-based management interventions. In this case for example, the data highlight the very large contribution of seine fishing to the overall reef fish yield (representing approximately 65% of landings) and thus six seine fishing vessels could be having a disproportionate impact on the reef fish resource. This information may provide sufficient evidence to shift the focus of current reef fishery management regulations from its current focus on fish traps and trammel nets alone [7] to other gears. Although demersal reef fish only account for roughly 10% of seine fishing catch, absence of data on the status of both demersal reef fish and the main target pelagic reef fish *Selar crumenophthalmus* suggests that assessing the seine fishery impacts on these species groups is warranted.

4.3. Applicability to SIDS fisheries management

The concurrent high dependency on coral reef ecosystem services and ecological impacts of reef fisheries highlight the importance of applying ecosystem approaches to reef fisheries management [8], particularly within SIDS. Within many Caribbean SIDS, there are currently efforts to increase the adoption of such approaches in marine resource management [59,60]. Nonetheless, the data requirements for approaches such as EAF are greater than those of traditional fisheries management, particularly given the spatial complexity of many coastal SIDS fisheries [7].

The spatial and seasonal data compiled in this study can make a valuable contribution in support of EAF in SIDS reef fisheries, particularly in management planning and the design of new interventions. For example, reef fisheries in Barbados are representative of many SIDS reef fisheries where marine spatial planning could be an effective management approach given the relatively small home-ranges of reef fish populations, high threats to the coral reef habitat, dearth of information on fish stock status, and conflicts of use in many areas (e.g. [61–63]). Many SIDS, including Barbados, are signatories to the Convention on Biological Diversity which requires that 10% of coastal and marine areas be 'equitably and effectively' managed within protected areas by 2020 [64]. Several Caribbean SIDS are aiming to protect an even higher proportion (20%) of their reefs by 2020 under the Caribbean Challenge Initiative [65]. As such, many Caribbean SIDS, including Barbados are in the process of creating a network of marine managed areas. Our data provide decision makers in Barbados with spatially-explicit information regarding the coral reef areas under heavy fishing pressure that may need greater management attention within a proposed network. By disaggregating fishing activity across space, time and by gear, the relative importance and differential impacts of select fishing activities can be clearly identified, especially when combined with simple biological indicators to assess fishery impacts on coral reefs [66].

As a visualisation method, map products can also be effective communication tools to engage and interact with fisheries and other marine stakeholders, facilitate data feedback and validation, and allow stakeholders to participate in decision-making processes [15,63,67]. These data also support socioeconomic monitoring of the various reef fisheries, where repeated assessments could shed light on the spatial and temporal dynamics of the fisheries [42], fisher responses to management interventions or shocks, and the socioeconomic implications of protection measures on various fisheries stakeholders [68].

It is recognized that the limited human and technical capacity with many SIDS fisheries management agencies [69,70] may limit their ability to collect, input and organize fisher interview data in a geo-spatial platform. Thus some technical support and capacity development for data collection and spatial data handling might be needed for some of the steps used in this study. Nonetheless, many of the tools and approaches used in this study (e.g. seasonal calendars) are adapted from widely used tools like the SocMon methodology, a social monitoring protocol implemented in over 60 sites in 30 countries worldwide [71], many of which are SIDS [72]. This study shows that with minor modifications, such socioeconomic and fisheries interview data can be combined with mapping exercises to generate informative data and maps for management [15]. These fisheries data can also be integrated with spatial information on demand for other ecosystem services (e.g. reef tourism) collected using other participatory methods [39,63]. The resulting information would represent useful inputs for a participatory multi-criteria analysis to identify the optimal design for marine spatial planning that balances ecosystem service demand and biodiversity conservation [63,73,74]. In addition, most of the spatial analysis steps can be completed using open-source software such as the statistical software R. A sample of the R code that was used to generate the maps shown here (Figs. 2–4) is provided online for easy access (http://rpubs.com/dgill/spatialfisheriesdata). At the most basic level, users only need to supply the fishing area polygons for each fisher, vessel or marine activity, and the estimated annual and seasonal intensity values associated with each polygon (Fig. 1).

Fisher interview data are likely to be limited in both precision and accuracy (see Section 2.6). As with our Barbados case study, to improve the accuracy of the data, it is recommended that researchers conduct concurrent observational studies on a sample of fishing vessels to validate fisher responses. Data validation exercises with key informants or focus groups are also recommended. Where possible, researchers may also want to compare their results to specific variables within official landings data. For example, the official recorded average trip catch might be an appropriate comparator even if official recording events are too inconsistent to measure trip frequency. Such comparisons however should take into account the nuances and limitations associated with the official landings data of interest.

5. Conclusion

As demand increases for limited marine resources, small-scale fisheries will continue to play a critical role in the livelihoods and food security for millions living in coastal communities around the world [75]. In the absence of data on these important fisheries, this study demonstrates how fisher interview data can provide insight into the seasonal and spatial distribution of reef fishing activity, revealing specific fisheries and fishing areas in need of immediate management attention. Despite limited capacity in many SIDS, with some support, management agencies can adopt the simple, low-cost data collection approaches demonstrated here to generate baseline data in support of informed and participatory decision-making, and ultimately, the sustainable management of marine ecosystems.

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Supplemental Table 1. Major types of reef fishing activities and target species in Barbados (adapted from Gill 2014).

Category		Description of fishing activity/gear/species
Fishing Type	Line fishing	Fishers use a handline, weight, and hooks to target reef species near the seafloor or in mid-water. Commercial fishers usually set from a boat and recreational/subsistence fishers may set from a boat or cast from shore with very few using a fishing rod. Few fishers in the sample also "troll" using a line towed behind a moving vessel where the line remains close to the surface to targets epipelagic reef-associated species (e.g. barracuda (Sphyraenidae)).
	Seine fishing	Fishers use a seine net from a boat and target schooling pelagic or demersal reef fish species. See [27] for more details.
	Spear fishing	Fishers use a speargun, sling or similar device to capture fish and/or to manually harvest benthic species such as conch, lobster, crab or octopus with or without the assistance of SCUBA gear. May use a boat or swim from shore. See [28] for more details.
	Trap fishing	Fishers use a trap or 'pot' usually made of wire mesh with a wooden frame and at least one specially shaped entrance funnel. These traps are usually placed on the seafloor and left to "soak" for a few days to attract and trap fish and/or lobster. See [26] for more details.
Target species / species group	Demersal reef finfish	Benthic reef fish species captured in depths of less than 50m (e.g. snappers (Lutjanidae), groupers (Serranidae), parrotfishes (Scaridae), and grunts (Haemulidae)). Vulnerable to multiple gear types including lines, spears, nets and traps.
	Reef-associated pelagic finfish	Coastal pelagic species found and caught on, or in close proximity to reefs. Usually harvested with a net (e.g. horse-eye jacks, scad (Carangidae), barracuda (Sphyraenidae)).
	Conch	Conch (usually *Strombus gigas*) gathered from seafloor by free-diving or SCUBA diving.
	Lobster	Lobster (mainly *Panulirus argus*) gathered from seafloor by free-diving, SCUBA diving or in traps.
	Other	Mainly invertebrate species found in and around reefs or near shore (e.g. octopus, crabs), gathered by free-diving/wading, SCUBA diving or in traps.