Determining Effective Fisheries Monitoring and Assessment Approaches in Data-limited Contexts: A Case Study of the Fisheries in Montserrat and Curaçao

La Determinación de un Método Eficaz para Monitorear y Evaluar la Pesca en un Contexto de Información Limitada: Un Estudio de Caso de las Pesquerías en Montserrat y Curaçao

La Détermination d'un Suivi Efficace de La Pêche et de L'approche de L'évaluation dans un Contexte de Données Limitées: Une Étude de la Pêche à Montserrat et Curaçao

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ABSTRACT

Science-based fisheries management requires accurate assessments of the status of marine resources, which depend on appropriate fisheries monitoring strategies. Given resource limitations, identifying the most effective monitoring and assessment approach for a fishery can pose a significant challenge. There is a growing body of literature on fishery assessment methods for data-limited contexts. However, there are few published examples of successful applications of these data-limited methods as a tool for informing small-scale fishery management. We present the first stages of monitoring strategies and preliminary results of data-limited fisheries analyses on two Caribbean islands: Montserrat and Curaçao. Although both islands have limited amounts of existing fisheries data, we found that each island required a different approach to monitoring due to differences in their fisheries' characteristics. Curaçao is a large and more developed island with dispersed landing sites and no existing fisheries monitoring, and thus requires a more detailed characterization of the fishery in order to design an appropriate monitoring plan. On the other hand, Montserrat is a small island with one main landing site and a long-term catch monitoring program, allowing us to conduct analyses on existing data and expand the current monitoring program to include additional information. We provide preliminary results from length-based analyses for several key target species on Montserrat, including red hind (*Epinephelus guttatus*), blue tang (*Acanthurus coeruleus*), and squirrelfish (*Holocentrus adscensionis*). We discuss fishery-dependent and fishery-independent monitoring options available on each island as well as approaches for integrating both data types. We also review lessons learned from the two case studies and how factors such as existing information, fishery management goals, available resources, and local capacity will inform next steps.

KEY WORDS: Fisheries monitoring, data-limited, fishery-dependent data, fisheries management, small-scale fisheries

INTRODUCTION

Fisheries are often managed using a harvest strategy to meet a defined management objective (Dowling et al. 2015). Three main components of a harvest strategy are monitoring, assessment, and decision or control rules (Sainsbury et al. 2000, Punt et al. 2002, Dowling et al. 2015). Monitoring the fishery is required to obtain data, which can then be used to assess the stock. Once an estimate of the stock status is known, managers can determine appropriate harvest levels and methods to control harvest (Butterworth and Punt 2003). Small-scale coral reef fisheries in developing countries often lack the resources required for adequate fisheries monitoring and thus do not have the data needed to conduct traditional stock assessments (Cochrane et al. 2011). For this reason, most small-scale fisheries remain unassessed (Costello et al. 2012), complicating efforts to determine appropriate management actions. Effective management is essential for these fisheries as they provide a source of income and protein for many local communities (Cochrane et al. 2011).

A number of data-limited stock assessment methods have been developed in an effort to improve fisheries management in small-scale, data-limited fisheries (reviewed in Honey et al. 2010, Fujita et al. 2013). Most of these methods require a time series of catch data or information on the length composition of the population, which is used to provide an estimate of the current stock status (Fujita et al. 2013). The Catch-MSY method (Martell and Froese 2012) is one such approach, providing an estimate of a stock's sustainable yield given a time series of at least 10 years of catch data, an estimate of the species' resilience score (Musick 1999), and an estimate of the relative depletion levels at the beginning and end of the time series (Martell and Froese 2012). This method works under the assumptions that catch represents all removals in a fishery and that the fishery has been fully exploited.

Fisheries scientists have also developed a number of length-based assessment methods, utilizing life history information and data on the length composition of the catch to determine stock status (*e.g.* Beverton and Holt 1956, Ehrhardt and Ault 1992, Gedamke and Hoenig 2006, Hordyk et al. 2015a). Length-based analyses are not appropriate for short-lived, fast-growing species, such as many pelagic or coastal pelagic species, because of the inability to distinguish age classes using length (Gulland and Rosenberg 1992). Most length-based methods rely on the assumption that stocks are in equilibrium (*i.e.*, mortality rates and recruitment are constant across time). These methods are also sensitive to life history parameter inputs (Fujita et al. 2013). A major advantage of length-based analyses is that they can provide a snapshot of stock status without a time series of data, assuming the input data are representative of all spatial and temporal aspects of the population (Fujita et al. 2013, Nadon et al. 2015). Additionally, length data tend to be relatively simple and inexpensive to collect

(Gulland and Rosenberg 1992).

The Blue Halo Initiative is a partnership between the Waitt Institute and local governments and stakeholders in Caribbean islands to develop science-based, community-driven solutions for sustainable ocean management. In February 2015, two new Blue Halo partnerships were formally launched: the islands of Montserrat and Curaçao. As part of its comprehensive approach to sustainable ocean management, the Blue Halo Initiative emphasizes effective fisheries management. The current study uses a science-based approach to determine appropriate fisheries management strategies for both islands. We found that the first step in identifying appropriate fisheries management strategies was to determine the status of key fishery stocks through analyses of fishery monitoring data. Although the availability of existing data differed at each site, we concluded that the collection of length composition data for target species would provide useful information for determining the current status of key fisheries stocks and add value to the fisheries management strategy in both sites.

In June 2015, we launched a pilot length composition monitoring program for selected target species in both Montserrat and Curaçao. This pilot program involved an initial, intensive monitoring effort over seven days at each site. In Montserrat, the initial intensive sampling has been followed by a less intensive monthly monitoring effort, which will continue over a 12-month period (June 2015 - June 2016) to ensure accurate representation of seasonal trends in the size composition of the target fish stocks. Once adequate sample sizes of length composition data have been collected, we plan to incorporate the length data, along with other existing data sources at each island, into data-limited assessments to determine the current status of key fishery stocks. Information on stock status could then be used to inform management decisions and determine appropriate harvest levels for the future. In this paper, we present preliminary assessment results and lessons learned from our initial length composition monitoring effort in June 2015. Importantly, this paper presents a general framework that can be applied for monitoring and assessing small-scale fisheries in data-limited situations.

METHODS

Description of Study Sites

Montserrat is a small, volcanic island located in the northeastern Caribbean Sea, forming part of the Leeward Islands in the Lesser Antilles island chain (Cook et al. 1981). There are currently an estimated 30 active fishers in Montserrat (personal observation). Fishers use multiple gear types to land more than 200 different species of fish and invertebrates (Ponteen 2014). Over the past two decades, about 46% of the landings by weight have been pelagic or coastal pelagic species, while 54% have been reef and demersal species (Montserrat Fisheries Unit, unpublished data). Red hind (*Epinephelus guttatus*) and queen triggerfish (*Balistes vetula*) are the top landed reef/demersal species by weight and are targeted primarily by fish traps. Although gar (*Tylosurus crocodilus*) and ballyhoo (*Hemiramphus brasiliensis*) landed with beach seine nets account for the largest portion of landings by weight, fish traps are the most frequently used fishing method (CRFM 2012). Traps are set all along the island's coast in depths of 15 to 100 meters and are typically left to soak for a minimum of 3 days (Wild et al. 2007). Almost all fish are landed at one site in Montserrat, Little Bay, and then taken to the nearby King's Market to be sold (personal observation). The Montserrat Fisheries Unit has collected data on landings weight since at least 1976 (Jeffers 1984). Detailed data, including information on catch, effort, and the taxonomic composition of landings, have been collected since 1994. To date, no formal assessment has been conducted on Montserrat's fisheries, and the status of reef fish stocks is unknown. Currently, no specific fisheries regulations to manage Montserrat's fisheries have been implemented.

Curaçao is the largest of the Dutch Caribbean islands, located 60 km north of Venezuela in the southern Caribbean Sea (Bruckner and Bruckner 2003). As of 2002, there were 111 active fishing vessels in Curaçao (Dilrosun 2002). The island has two main fisheries: a troll fishery targeting pelagic fish and a reef fishery targeting demersal and reef species (Dilrosun 2002). The troll fishery accounts for about 70% of total landings, while the reef fishery accounts for 10 - 15% of the catch (Dilrosun 2002, Leenstra 2005). The reef fishery primarily uses handlines and traps, and barracuda (*Sphyraena* spp.), parrotfish (Scaridae), snappers (Lutjanidae), and triggerfish (Balistidae) are the most frequently landed species (Schultink and Lindenbergh 2006). Fifteen main fishery landings sites are located along Curaçao's coast (Dilrosun 2002), but fishers also land their catches in additional, undesignated locations (personal observations). Currently, Curaçao does not have a long-term fishery monitoring program in place, but government agencies and scientists have undertaken several short-term fishery-dependent and fishery-independent monitoring programs in the last fifteen years. Although no formal assessment of Curacao's fisheries has been conducted to date, evidence from surveys suggests that Curacao's reef fisheries may have experienced overexploitation (Sandin et al. 2008). Curaçao currently has several fisheries management policies in place: gillnets and trammel nets are banned in waters of less than 60 meters depth without a permit; spearfishing is prohibited except when targeting lionfish; fish traps must have escape gaps; and there are protections for gravid and molting lobsters (Vermeij and Chamberland 2012). Nevertheless, these regulations are poorly implemented and enforced (Schultink and Lindenbergh 2006).

Review of Existing Data and Target Species Identification

We began by identifying all available fishery-independent and fishery-dependent data in Montserrat and Curaçao. The Montserrat Fisheries Unit has electronically available fishery-dependent data on the landed weight of catches, identified to the species, genus, or family level, from 1994 through the present. In Curaçao, independent researchers and staff at the Ministry of Health, Environment, and Nature collected data from short-term fishery-dependent monitoring programs in 2002, 2004, and 2005 (Dilroson 2002, Leenstra 2005, Schultink and Lindenbergh

2006). Fishery-independent survey data are also available from surveys conducted in 2009 and 2011.

Length-based analytical methods are appropriate for species that are relatively slow-growing and long-lived; these methods are typically applied to coral reef and demersal species (Ault et al. 2008; Nadon et al. 2015). It is difficult to infer an individual's age from its length for species that are fast-growing and short lived, a life history strategy commonly observed in pelagic and coastal pelagic species. For this reason, we selected only coral reef and demersal species to target for monitoring and assessment. Two factors were considered to identify target species:

i) The relative importance of the species in the fishery (by landed weight or abundance), based on the available data and local, expert knowledge, and
ii) The availability of life history information for the species (Table 1).

Species Length Composition Sampling

In June 2015, we collected length composition data of target species at each site for seven days. In Montserrat, where there is only one landing site, we attempted to sample 100% of all fishing trips. In Curaçao, we used available fishery-dependent data to determine the relative amount of reef fish landings by landing site. Based on this analysis, we determined the relative time we would spend sampling at each landing site. We measured the lengths of individual fish using a measuring board and recorded the lengths to the nearest 0.5 cm. We took measurements of total length for all parrotfish (Scaridae) and grouper (Serranidae) species and fork length measurements for all other species.

We summarized the length composition data collected for target species in Montserrat and Curaçao, including only the species that had a minimum of 15 length observations over at least five fishing trips in the length-based analyses (Ault 2013). For the species that met the minimum data requirements, we compiled a database of life history parameters (growth, longevity, and resilience score) specific to the Caribbean region from relevant literature (Table 2). We calculated natural mortality rates (M) for each species based on longevity (t_λ) (Alagaraja 1984; Hewitt and Hoenig 2005), with the assumption that five percent of the cohort survived to t_λ (Nadon et al. 2015):

$$M = \frac{-\ln(0.05)}{t_\lambda} \quad (1)$$

To estimate the length at which 50% of the population has reached maturity (L_{m50}), we used Froese and Binohlan's empirically derived formula relating asymptotic length to length at first maturity (Froese and Binohlan 2000):

$$\log L_{m50} = 0.8979 * \log(L_{\inf}) - 0.0782 \quad (2)$$

To estimate the length at 95% maturity (L_{m95}), we applied the following equation (Froese 2006; Sow et al. 2010) :

$$L_{m95} = L_{m50} * 1.14 \quad (3)$$

Length-Based Analyses

We applied two length-based analyses to the length data for species meeting the minimum data requirements: the average length ($\bar{L}$) method (Ehrhardt and Ault 1992) and the length-based spawning potential ratio (*LB-SPR*) method (Hordyk et al. 2015a). Both length-based methods assume that the species' population is in equilibrium and that the length data included in the analyses are representative of the entire population.

For exploited species, $\bar{L}$, or the average body size (length) of the exploited population, can be used to estimate the rate of instantaneous fishing mortality, or F (Ehrhardt and Ault 1992. As F increases, fewer fish reach larger sizes, causing a decrease in the mean value of the exploited size frequency distribution:

$$\bar{L} = \frac{Z(L_c - \bar{L}) + k(L_{inf} - \bar{L})}{Z(L_\lambda - \bar{L}) + k(L_{inf} - \bar{L})} \quad (4)$$

Where L_c is the minimum length that is fully selected by the fishery, L_λ is the length corresponding the species' maximum exploitable age, Z is total mortality, and L_{inf} and k are von Bertalanffy growth parameters.

Table 1. List of target species identified for monitoring and assessment in Montserrat and Curaçao. Target species were identified based on: 1. relative fishery importance (using available fishery-dependent data and local, expert knowledge), and 2. availability of life history parameters.

Montserrat		Curaçao	
Scientific Name	**Common Name**	**Scientific Name**	**Common Name**
Balistes vetula	queen triggerfish	*Balistes vetula*	queen triggerfish
Caranx ruber	bar jack	*Caranx ruber*	bar jack
Cephalopholis fulva	coney grouper	*Cephalopholis fulva*	coney grouper
Epinephelus guttas	red hind	*Cephalopholis cruentata*	graysby grouper
Lutjanus mahogoni	mahogany snapper	*Lutjanus buccanella*	blackfin snapper
Lutjanus synagris	lane snapper	*Ocyurus chrysurus*	yellowtail snapper
Lutjanus vivanus	silk snapper	*Mulloidichthys martinicus*	yellowbar goatfish
Acanthurus coeruleus	blue tang	*Scarus taeniopterus*	princess parrotfish
Acanthurus chirurgus	doctorfish	*Seriola dumerili*	greater amberjack
Holocentrus adscensionis	squirrelfish	*Sparisoma aurofrenatum*	redband parrotfish

The length composition of an exploited stock is determined by the ratios of natural mortality to growth rate (M/k) and the fishing mortality to natural mortality rate (F/M) for the stock (Hordyk et al. 2015b). When L_{inf} is known, the ratio of Z/k can be determined from the length structure of the catch. If M is known, F can then be calculated:

$$Z = M + F \tag{5}$$

We assumed that fishing mortality at maximum sustainable yield (F_{MSY}) was equal to the species' natural mortality rate (M) (Quinn and Deriso 1999:)

$$F_{MSY} = M \tag{6}$$

We calculated relative fishing mortality (F/F_{MSY}) for each species using the $\bar{L}$ and *LB-SPR* methods.

Table 2. Life history parameter values, references, and study locations for 6 target species in Montserrat. Parameter values listed were used in length-based and catch-based analyses.

Species	Parameter	Value	Units	Reference	Location
A. chirurgus (doctorfish)	L_{inf}	36.69	cm (FL)	Kishore and Chin 2001	Montserrat
	k	0.08	year^{-1}		
	t_0	-4.31	-		
	Longevity (t_λ)	27	years		
	Natural mortality (M)	0.11	year^{-1}	calculated, see eq. 1	
	Length at maturity (L_{m50})	21.21	cm (FL)	calculated, see eq. 2	
	Length at maturity (L_{m95})	24.18	cm (FL)	calculated, see eq. 3	
	Resilience Score	low	-	Musick 1999	
A.coeruleus (blue tang)	L_{inf}	23.1	cm (FL)	Mutz 2006	San Blas Islands, Panama
	k	0.49	year^{-1}		
	t_0	-0.25	-		
	Longevity (t_λ)	16	years		
	Natural mortality (M)	0.19	year^{-1}	calculated, see eq. 1	
	Length at maturity (L_{m50})	14.00	cm (FL)	calculated, see eq. 2	
	Length at maturity (L_{m95})	15.96	cm (FL)	calculated, see eq. 3	
	Resilience Score	medium	-	Musick 1999	
B. vetula (queen triggerfish)	L_{inf}	41.50	cm (FL)	Manooch and Drennon 1987	Puerto Rico and US Virgin Islands
	k	0.30	year^{-1}		
	t_0	-0.60	-		
	Longevity (t_λ)	7	years		
	Natural mortality (M)	0.43	year^{-1}	calculated, see eq. 1	
	Length at maturity (L_{m50})	23.69	cm (FL)	calculated, see eq. 2	
	Length at maturity (L_{m95})	27.01	cm (FL)	calculated, see eq. 3	
	Resilience Score	medium	-	Musick 1999	
C. guttatus (red hind)	L_{inf}	55.78	cm (FL)	Sadovy et al. 1992	Puerto Rico and St. Thomas
	k	0.09	year^{-1}		
	t_0	-3.82	-		
	Longevity (t_λ)	17.5	years		
	Natural mortality (M)	0.17	year^{-1}	calculated, see eq. 1	
	Length at maturity (L_{m50})	30.9	cm (FL)	calculated, see eq. 2	
	Length at maturity (L_{m95})	35.22	cm (FL)	calculated, see eq. 3	
	Resilience Score	medium	-	Musick 1999	
H. adscensionis (squirrelfish)	L_{inf}	52.23	cm (FL)	Estimated using FishBase	NA
	k	0.34	year^{-1}		
	t_0	-0.40	-		
	Longevity (t_λ)	8.4	years		
	Natural mortality (M)	0.36	year^{-1}	calculated, see eq. 1	
	Length at maturity (L_{m50})	29.13	cm (FL)	calculated, see eq. 2	
	Length at maturity (L_{m95})	33.21	cm (FL)	calculated, see eq. 3	
	Resilience Score	medium	-	Musick 1999	
L. mahogoni (mahogany snapper)	L_{inf}	58.89	cm (FL)	Ault et al. 1998	Florida Keys
	k	0.10	year^{-1}	Ault et al. 1998	
	t_0	-1.73	-	Ault et al. 1998	
	Longevity (t_λ)	10	years	Ault et al. 1998	
	Natural mortality (M)	0.30	year^{-1}	calculated, see eq. 1	
	Length at maturity (L_{m50})	32.44	cm (FL)	calculated, see eq. 2	
	Length at maturity (L_{m95})	36.98	cm (FL)	calculated, see eq. 3	
	Resilience Score	low	-	Musick 1999	

In addition, we calculated the spawning potential ratio (*SPR*), or the proportion of the unfished reproductive potential left at any given level of fishing pressure, of the stocks, using information on the ratios of M/k, F/M, length at maturity (L_m) to L_{inf} (L_m/L_{inf}), and the length of knife edge selectivity (L_c) to L_{inf}, using equations from Hordyk et al. (2015b). We compared the *SPR* values calculated for each species using the *LB-SPR* method to an *SPR* of 30%, a commonly used reference point in fisheries management (Nadon et al. 2015).

Catch-Based Analysis

We summarized data on the annual total catch (in kg) of target species in Montserrat. Using a method described by Martell and Froese (2012), Catch-*MSY*, we estimated maximum sustainable yield (MSY) for each target species. This method requires a species' resilience score (Musick 1999), a minimum of 10 years of catch data, and knowledge of the relative stock status at the beginning and end of the time series of catch data. Using the species resilience scores, we identified a range of potential values for the intrinsic growth rate (r) of each species. We used information on the maximum historical catch and relative stock status to determine the range of potential values for each population's carrying capacity (K). We then used a Schaefer surplus production model to determine r-K pairs that do not cause the population to collapse or exceed carrying capacity, given the population's catch histories (Schaefer 1954):

$$B_t = rB_t\left(1 - \frac{B_t}{K}\right) - C \qquad (7)$$

Where B is biomass at time t, and C is the total catch at time t. We calculated the median value of these r and K pairs to estimate the following management reference points: maximum sustainable yield (*MSY*), biomass at MSY (B_{MSY}), and fishing mortality at MSY (F_{MSY}):

$$MSY = \frac{1}{4}rK \qquad (8)$$

$$B_{MSY} = \frac{1}{2}K \qquad (9)$$

$$F_{MSY} = \frac{1}{2}r \qquad (10)$$

Finally, we calculated annual instantaneous fishing mortality (F) as:

$$F = -ln\left(1 - \left(\frac{C_t}{B_t}\right)\right) \qquad (11)$$

RESULTS

Montserrat

In total, we measured 386 individual fish from a total of 16 fishing trips, including length measurements for all ten target species. We surveyed an estimated 87% of all target species landed during the 7 days of sampling and obtained length measurements from all but one fishing trip returning to Little Bay from June 16 to 21, 2015 (Table 3a). Red hind (*E. guttatus*) had the largest number of individual length measurements (n=108), and redtail parrotfish (*Sparisoma chrysopterum*) had the least number of length measurements (n=4). Out of our 10 target species, 6 species met the criteria required to conduct length-based analyses: 15 length observations coming from a minimum of 5 trips. We created length composition density plots for each species that met the minimum data requirements for length-based analyses, indicating the length at first maturity and asymptotic length for each species (Figure 1).

Figure 2 presents the historical catch data collected by the Montserrat Fisheries Unit and the *MSY* values estimated using the catch-based method for each of the 6 species included in the data-limited analyses. For all of the species except squirrelfish (*Holocentrus adscensionis*), landings peaked between 2002 and 2005, followed by a general pattern of decline (Figure 2). Squirrelfish catches showed a declining trend from the beginning of the time series. Landings for all species except mahogany snapper (*Lutjanus mahogoni*) showed a slight increase over the last three years, and landings for all species except squirrelfish and mahogany snapper fell within the 95% confidence intervals estimated for *MSY*, which fell below the estimated *MSY* in recent years.

The relative fishing mortalities (F/F_{MSY}) estimated for each species using the length-based analyses ($\bar{L}$ and *LB-SPR*) and the catch-based analysis are presented in Figure 3 The relative F (F/F_{MSY}) estimated by the catch-based method was consistently lower than the F/F_{MSY} estimated by the two length-based analyses. In general, the F/F_{MSY} values estimated by the length-based analyses were associated with large uncertainties, complicating efforts to determine whether a stock fell above or below the management reference point of $F/F_{MSY} = 1$. Both length-based analyses estimated the lowest relative F for queen triggerfish (*B. vetula*) and the highest relative F for blue tang (*Acanthurus coeruleus*) and squirrelfish. The lower 95% confidence intervals for relative F of blue tang and squirrelfish were greater than the management reference point. Meanwhile, the catch-based analyses estimated the relative F to be lowest for mahogany snapper and squirrelfish, and highest for red hind and doctorfish (*A. chirurgus*).

Spawning potential ratio values estimated using the *LB -SPR* method are presented in Figure 4. Squirrelfish had the lowest estimated *SPR* value, while queen triggerfish had the highest (Figure 4). For queen triggerfish, even the lower confidence interval for *SPR* was greater than the target management reference point (*SPR* = 30%). Every species except blue tang had upper confidence intervals for *SPR* that fell above the management reference point.

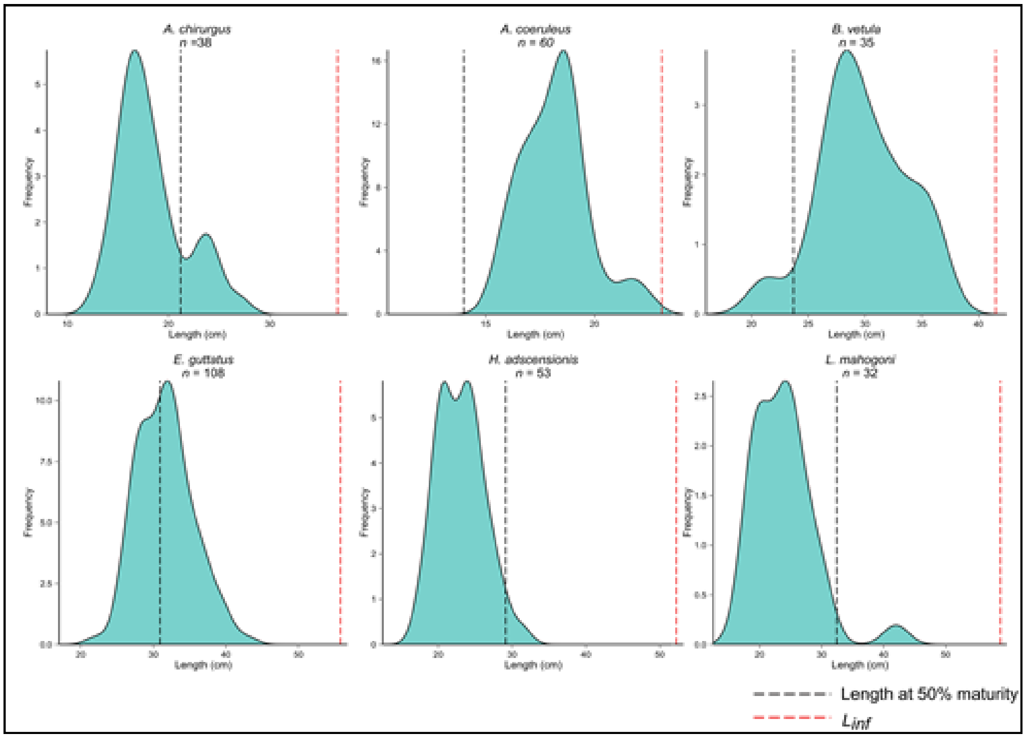

Figure 1. Fishery-dependent length frequency data collected from Montserrat in June 2015 for six target species. The number of individual lengths measured for each species (n) is indicated under the species' common name. The black dotted line indicates length at 50% maturity, and the red dotted line represents the species' L_{inf}..

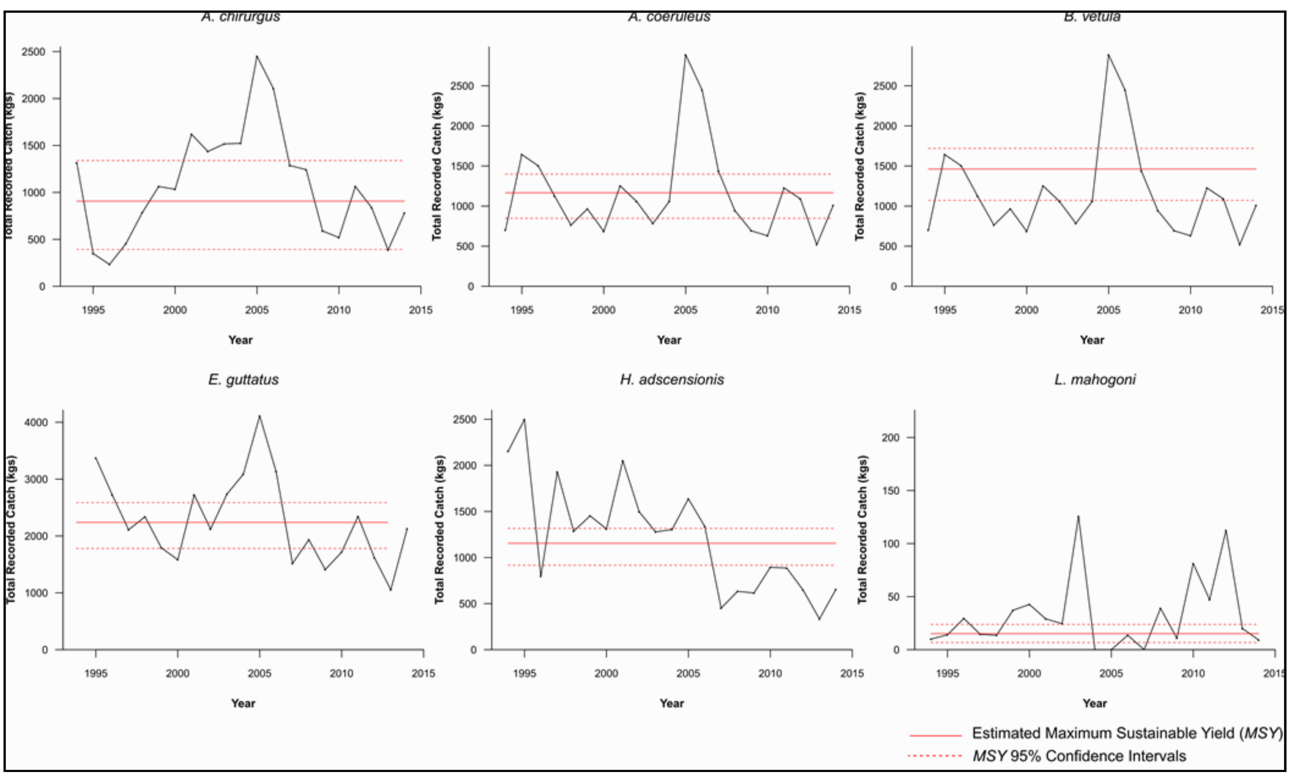

Figure 2. Annual landings data (black line) for 6 coral reef fishery species in Montserrat from 1994 - 2014, and estimated median *MSY* (red solid line) and 95% confidence intervals (red dotted lines) from the Catch-MSY analysis (Martell and Froese 2013). Sustainable yield and confidence interval values are presented in Table 4.

Curaçao

During the week of length composition sampling in Curaçao, we surveyed a total of 33 fishing trips. However, only 14 of the intercepted fishing trips had target species in their catch (Table 3b). Princess parrotfish (*Scarus taeniopterus*) had 40 individual length measurements, the largest sample size of any target species, but these measurements were from only two fishing trips. Queen triggerfish and blackfin snapper (*Lutjanus buccanella*) each had only a single length measurement. None of the target species in Curaçao met the minimum data requirements for the length-based analyses, and no catch data were available to conduct a catch-based analysis.

DISCUSSION

Although small-scale fisheries across the Caribbean face similar management challenges (Salas et al. 2006), our attempt to use a single approach for monitoring and assessing the fisheries in Montserrat and Curaçao illustrates the hurdles to implementing a standardized approach. Even within the same region, fisheries vary widely, and there is no 'one-size-fits-all' approach for effective small-scale fisheries assessment and management (Cochrane et al. 2011). Based on our experience, the initial steps in determining an effective monitoring program for a fishery should include a full characterization of the fishery and establishment of relationships and common goals with local managers and fishers. The amount of effort and appropriate approach required to completing these two tasks is likely to vary considerably depending on the characteristics of the fishery. In Montserrat, the spatial extent, number of participants in the fishery, and the availability of existing data allowed us to accomplish these tasks and successfully launch a species length composition monitoring program.

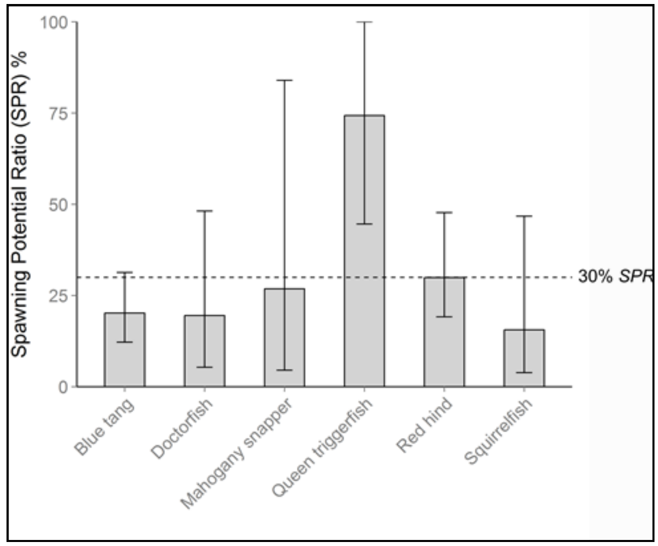

Figure 4. Spawning potential ratio (*SPR*, %) estimated for six coral reef fishery species in Montserrat. *SPR* was estimated using a length-based analysis (Hordyk *et al*. 2015), and length data collected in 2015 (Figure 1). Error bars represent 90% confidence intervals. USA federal standards define 30% *SPR* as the threshold below which a stock is no longer sustainable (Nadon 2015).

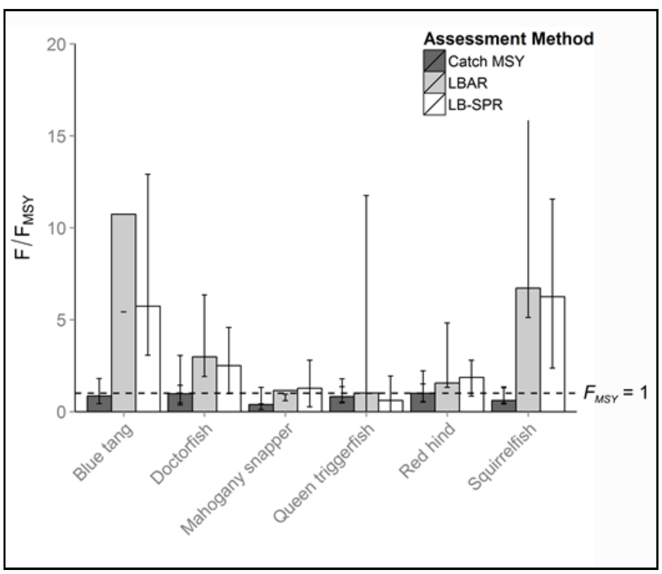

Figure 3. Current fishing mortality (*F*) over fishing mortality at maximum sustainable yield (F/F_{MSY}) for 6 coral reef species in Montserrat using 3 data-poor stock assessment methods: *LB-SPR* (white), $\bar{L}$ (light grey), and Catch-MSY (dark grey). Stocks with a ratio of $F/F_{MSY} > 1$ may be experiencing overfishing. Length-based analyses used fishery-dependent length data collected in 2015, and the catch-based analysis used fishery-dependent catch data from 1994 - 2014.

Table 3. The number of individual lengths (*n*) measured for target species and the number of fishing trips surveyed for each species in: a) Montserrat from June 15 - 21, 2015, and b) Curaçao from June 24 - 30, 2015. * indicates species that met the minimum data requirements to be included in the length-based analyses.

(A)			(B)		
Species	***n***	**# of trips**	**Species**	***n***	**# of trips**
*A. chirurgus**	38	9	*B. vetula*	1	1
*A. coeruleus**	60	8	*C. ruber*	12	4
*B. vetula**	35	6	*C. fulva*	10	3
C. ruber	8	2	*E. cruentatus*	28	4
C. fulva	18	4	*L. buccanella*	1	1
*E. guttas**	108	11	*O. chrysurus*	18	14
*H. adscensionis**	53	11	*M. martinicus*	11	4
*L. mahogoni**	20	7	*S. taeniopterus*	40	3
L. synagris	36	3	*S. dumerili*	3	2
L. vivanus	20	3	*S. aurofrenatum*	24	2

A major assumption of length-based methods is that the data fully represent the fish stock (Gulland and Rosenberg 1992). In Montserrat, because the fishers who land catches at Little Bay fish in areas all around the island, we assume that the length data collected at Little Bay are representative of the fish stock. However, results presented in this study only include data on catches that were landed in June 2015, which are likely not representative of all temporal and seasonal aspects of the stock. Data from a limited temporal scale may be biased: for example, it may capture the stock before or after an annual recruitment pulse, resulting in an inaccurate representation of the length composition of the entire stock and a large bias in the estimate of total mortality (Hoenig 1987). We anticipate that as monitoring continues over the next year and the seasonal trends of the fishery are captured, the results of our analyses will become more reliable and the uncertainty associated with the status of key fishery species will decrease.

The preliminary results from the catch- and length-based analyses of key fishery species in Montserrat demonstrate the potential impacts that monitoring more than one stream of data may have for management decisions that occur in a fishery. Monitoring fisheries using multiple data sources can reduce management uncertainty, and provide a better understanding of the fishery (Honey et al. 2015; McDonald et al. 2015). Although we are not able to determine with any certainty the status of key fisheries species in Montserrat from the results presented here, it is clear that estimates of relative fishing mortality were substantially lower for the analyses that used catch data and higher for the analyses that included length data. This may stem from uncertainty or bias associated with the data. Our length data do not currently represent the full temporal extent of the stock; it is possible that catch- and length-based results will converge as more length data are collected. The differences in results may also be attributed to the different assumptions associated with each analysis. The length-based analyses are highly sensitive to life history input parameters (Nadon et al. 2015), while the catch-based analyses assume that the total catch represents all removals in a fishery and that the fishery has been fully developed (Martell and Froese 2012). The most dependable data and appropriate analyses may vary by species, underscoring the importance of developing a comprehensive understanding of the fishery prior to interpreting results.

In Curaçao, the absence of a comprehensive understanding of the characteristics of the fishery undermined our efforts to use length composition monitoring to determine the status of key fishery species. The lack of information on the characteristics of Curaçao's fisheries makes it difficult to determine whether are data are representative of the fish stock, spatially and temporally. Therefore, the data are not currently suitable for length-based analyses. We have concluded the appropriate next step to monitor and assess Curacao's fisheries will include conducting a full characterization of the fishery. To complete this, plans are underway to identify all current fishery landings sites in Curaçao, conduct surveys of landing sites, and interview fishers. Once a full characterization of Curaçao's fisheries is complete, an appropriate fisheries monitoring and assessment plan can be identified and designed.

Although our results to date do not provide us with enough information to determine with certainty the current status of key fishery species in Montserrat and Curaçao, they do allow us to develop a framework for fisheries monitoring and assessment in data-limited situations and identify clear next steps for our work. As length and catch monitoring continues in Montserrat and we add new data to the analyses, we expect a higher degree of certainty in the results. As sample sizes for the length data increase and span a wider temporal scale, we will rerun the analyses and interpret the results in light of the models' assumptions and our increased knowledge of the fishery. While our work demonstrates the necessity of adapting fisheries monitoring and assessment plans to suit the local contexts of each individual small-scale fishery, we also provide general guidelines for this process, which can be applied beyond our study sites. (Figure 5). Through efficient monitoring and appropriate assessment methods, fisheries science can inform fisheries management, leading to better ecological and socioeconomic outcomes in resource-dependent communities.

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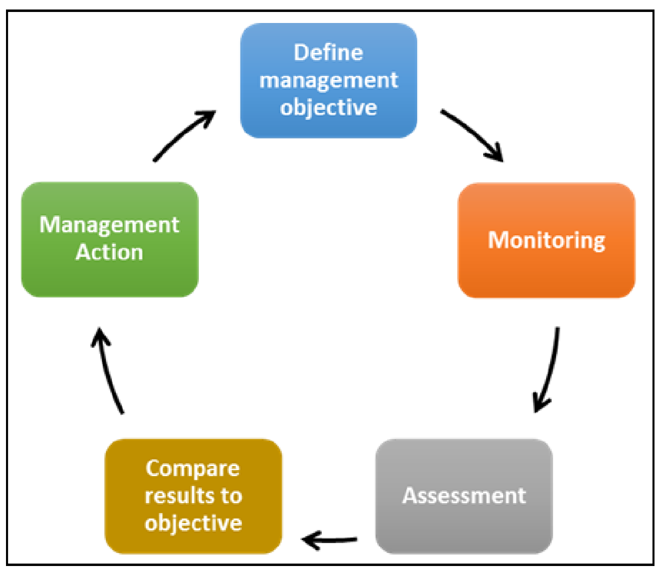

Figure 5. Framework for adaptive fisheries management, which includes the following steps: 1. Setting a management objective, 2. Monitoring the fishery, 3. Assessing the fishery, 4. Comparing results of assessment to management objective, and 5. Management action. This process can be completed on an annual basis or over a timescale that is appropriate for the resource (Wilson et al. 2014). This study focuses on the monitoring and assessment steps of the adaptive fisheries management framework in a small-scale, data-limited fishery setting.

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