FastTrack publication

Bull Mar Sci. 94(2):000–000. 2018
https://doi.org/10.5343/bms.2016.1127

research paper

Vulnerability of nearshore tropical finfish in Cuba: implications for scientific and management planning

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Date Submitted: 5 December, 2016.
Date Accepted: 18 September, 2017.
Available Online: 21 December, 2017.

ABSTRACT.—Coastal areas of Cuba harbor rich biodiversity that provide a variety of important ecosystem services, including fisheries production. High-value invertebrate fisheries in Cuba are managed on the basis of scientific assessments, but comparable data and analyses are lacking for the much larger number of exploited finfish species. However, dramatic declines in finfish catch despite minimal management restrictions suggests resource depletion, and the need for scientific and management attention. To prioritize finfish for such attention, we conducted productivity-susceptibility analyses (PSA) for 34 species within each of Cuba's four fishery management zones. The resulting 136 estimates of vulnerability to overfishing revealed few differences in species-specific scores among zones, despite ecological and socioeconomic heterogeneity along the Cuban coast. Vulnerability scores were generally low, although this relative metric does not necessarily mean that overfishing has not occurred. Spatial differences in catch composition relative to the vulnerability scores underscore potential differences in socioeconomic vulnerability of fishing communities based upon their reliance on different species. Therefore, our PSA results should be used to prioritize research, monitoring, and stock assessment efforts, as well as management actions, within each fishing zone to conserve locally important resources, recover those that are depleted, sustainably develop those that are underutilized, and promote ecological and socioeconomic stability across Cuba as it confronts the challenges of a changing world.

Effective management of marine fisheries requires scientific guidance on the status of resources relative to predefined targets or limit reference points for individual stocks or complexes of stocks (Mace 1994). Fishery managers are often challenged with maintaining sustainable levels of removals for long periods of time. This challenge is intensified in fisheries where multiple stocks of varying biological productivity and susceptibility to fishing pressure are caught together (Murawski 1991, Essington et al. 2006). As the number of stocks in need of management increases, the data and resources available typically limit the potential depth of analysis per stock (Reuter et al. 2010). Greater than 80% of the global catch occurs in fisheries that lack the necessary data, resources, infrastructure, and expertise to use conventional statistical stock assessment models to estimate biomass levels and maximum sustainable yield. Instead, these fisheries, which are often small-scale in nature, go unmanaged or are managed with little scientific input, resulting in suboptimal harvest rates, ineffective regulations, and poor social and economic outcomes for those dependent on fishing (Costello et al. 2012, 2016).

Nearshore and small-scale fisheries play an important role in the culture and economy of many island nations in the Caribbean Sea, including Cuba. There, a highly productive habitat mosaic of mangroves forests, seagrass meadows, and coral reefs support a diverse suite of fish and invertebrate species, and provide an array of ecosystem services (Kritzer et al. 2014). Management of these ecosystems and targeted stocks is critical to ensure a sustainable fishing future for Cuba. The Ministry of the Food Industry (Ministerio de la Industria Alimentaria, or MINAL) is the government agency responsible for all production and management of fishery resources. Thus, the fisheries of Cuba are state owned and managed under a centralized system. The Fisheries Research Center (CIP) is the scientific branch of MINAL, responsible for generating the necessary technical support for fishery management. CIP proposes regulations to the Directorate of Fishing Regulations. After the Advisory Commission on Fishing has analyzed and approved these regulations, they are submitted to the Minister of MINAL. Regulations approved by MINAL are published by decree law and controlled by the National Inspection Office.

Within Cuban waters, the majority of the fishing industry is organized into 14 state enterprises operating 705 boats among them, 385 of which are between 15 and 20 m in length and target finfish. All of the invertebrate species and approximately 90% of finfish are captured by the state sector. There are also 3603 smaller private boats, mostly <15 m in length, with commercial access to finfish under a strict contract regime with the state enterprises. The enterprises each have exclusive access to defined areas for fishing spiny lobster [*Panulirus argus* (Latreille, 1804)], shrimp (*Penaeus notialis* Pérez Farfante, 1967), sea cucumber [*Isostichopus badionotus* (Selenka, 1867)], and queen conch [*Lobatus gigas* (Linnaeus, 1758)]. In contrast, although most of the private vessels operate near their home ports, there are no analogous territorial use rights (TURFs) in the finfish fishery, which comprises approximately 150 different species (Valle et al. 2011). The most common fishing gears used in Cuban fisheries are seine nets, gillnets, traps, bottom and surface longlines, and hook and line. Set nets were banned in 2008 and trawls were banned in 2012. All of the coastal fisheries are managed within one of four management zones distributed across the Cuban coastal shelf (Fig. 1).

Stock assessments and effective management strategies have been formally adopted for the smaller number of invertebrate fisheries within these management zones, including lobster, shrimp, sea cucumber, and queen conch. Available scientific information for these invertebrate species includes biological and fishery-independent indices, catch and effort, size composition of the catch, and other metrics. This robust

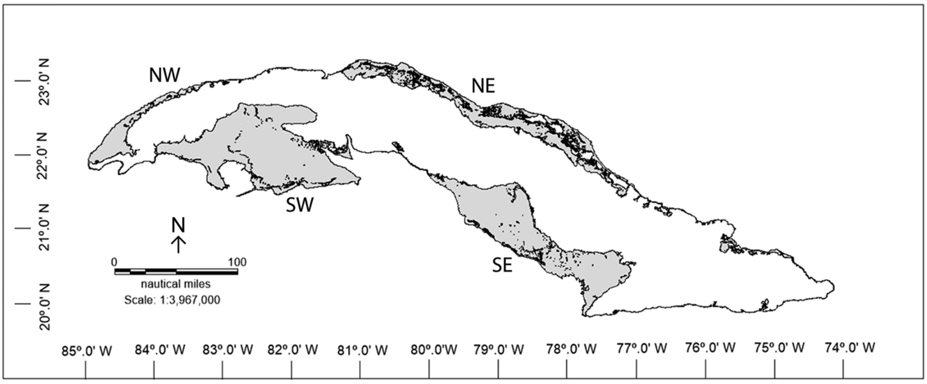

Figure 1. Fishery management zones of the Cuban shelf. SE: southeast, SW: southwest, NW: northwest, NE: northeast.

information base has enabled formal stock assessments and science-based harvest controls for invertebrates, such as catch and effort limits, closed seasons, and minimum legal sizes (Alfonso et al. 2004, Puga et al. 2005, González-Yañez et al. 2006, Formoso 2007, Alzugaray and Puga 2012, Giménez et al. 2012, Puga et al. 2013).

In contrast, the large number of landing ports and high diversity of vessel types, fishing gears, and target species make it much more difficult to develop and implement monitoring programs, and estimate fishing effort, reference points, and resource status across the Cuban finfish fishery. Previous estimates of status have been restricted to descriptions of the fishery and trends in the total finfish catch or catch of certain species or groups (Baisre 2000, 2018, Claro et al. 2001a, 2009, Valle et al. 2011). Consequently, the finfish fishery currently lacks formal stock assessments, and therefore only minimal management measures are in place, such as minimum legal sizes and the use of marine protected areas (MPAs; Kritzer and Liu 2013). This is especially problematic given that finfish now comprise the majority of the catch in Cuban fisheries (Table 1), despite total catch and effort having declined considerably from peaks in the mid-1980s (Fig. 2).

To develop priorities for scientific efforts and management actions that will improve the sustainability of Cuban finfish fisheries, we conducted productivity-susceptibility analyses (PSAs; Patrick et al. 2009). PSA allows species to be ranked based on their relative vulnerability to overfishing, with more vulnerable species then prioritized for data collection, stock assessments, or conservation and management interventions (Fujita et al. 2013). Furthermore, in light of the geographic, ecological, and socioeconomic heterogeneity across the coastal and marine areas in Cuba, we conducted separate PSAs for each of Cuba's four fishery management zones. This approach buffers against assuming homogeneous conditions across the country, and in so doing enables a unique spatial comparison of species vulnerability within a single country and greater insight into the local determinants of vulnerability.

Materials and Methods

The four costal zones in Cuba constitute relatively independent fishing areas for management purposes (Fig. 1). Two of these zones are on the south side of Cuba, including the southeast zone spanning the Gulf of Ana María and Gulf of Guacanayabo,

Table 1. Percentage of total catch for major taxonomic groups in Cuban fisheries during four periods. Data for 1981–1995 from Claro et al. 2001a; data for 2013–2015 from Ministry of the Food Industry.

	1981–1985	1986–1990	1991–1995	2013–2015
Finfish (total)	37.2	38.8	42.5	61.9
Nearshore teleosts				48.9
Small tuna				4.0
Sharks and rays				9.0
Crustaceans (total)	25.7	22.6	25.0	26.8
Lobster	17.3	14.9	18.0	20.3
Shrimp	6.8	5.3	4.7	3.3
Other Crustacea	1.6	2.4	2.2	3.1
Mollusks (total)	6.1	5.7	6.3	9.8
Oysters	3.7	3.2	3.2	5.6
Queen conch	0.8	0.3	0.1	2.5
Clams	2.0	2.2	3.0	1.7
Sponges	0.1	<0.1	0.1	0.2
Turtles	1.4	1.1	0.6	0.0
Sea cucumber	0.0	0.0	0.0	1.1
Bycatch	27.9	31.3	25.3	0.2
Other	1.6	0.4	0.2	0.0
Finfish + bycatch	65.1	70.1	67.8	62.1
Total catch (metric tons)	68,743.8	71,476.1	51,862.4	21,350.6

and the southwest zone spanning the Gulf of Batabanó. The other two smaller and narrower zones are on the north coast, including the waters surrounding the Los Colorados Archipelago in the northwest, and the waters surrounding the Sabana-Camagüey Archipelago in the northeast.

PSA was originally developed to assess the sustainability of bycatch in the Australian prawn fishery (Milton 2001, Stobutzki et al. 2001). The modified methodology by Patrick et al. (2009) is used to assess the vulnerability of a stock to overfishing based on the combination of its inherent biological productivity and the nature of its interactions with fishing fleets that determine its susceptibility to overfishing. PSA has been widely used for assessing vulnerability in US and European fisheries (Patrick et al. 2009, Cope et al. 2011, Ormseth and Spencer 2011, McCully et al. 2013). This method semi-quantitatively estimates species' productivity and susceptibility based on available life history, population, ecological, and fishery information. The overall vulnerability score for each stock is calculated as the Euclidean distance from the origin in a plot of the productivity and susceptibility scores.

We conducted PSAs for 34 finfish species found within each of Cuba's four fishery management zones. We assumed that the population of a given species within a given management zone constitutes a distinct stock, which is a reasonable assumption given that many of our species of interest exhibit limited movements, and the distances among management zones and other geographic attributes promoting separation (Fig. 1). However, stock boundaries have not been delineated for any finfish species in Cuba, and many likely deviate to varying degrees from the management zone boundaries given patterns of larval dispersal, adult movement, and habitat use. Substantial deviation from this assumption might constitute a critical limitation of the analysis. In total, we produced 136 stock-specific estimates of vulnerability. The

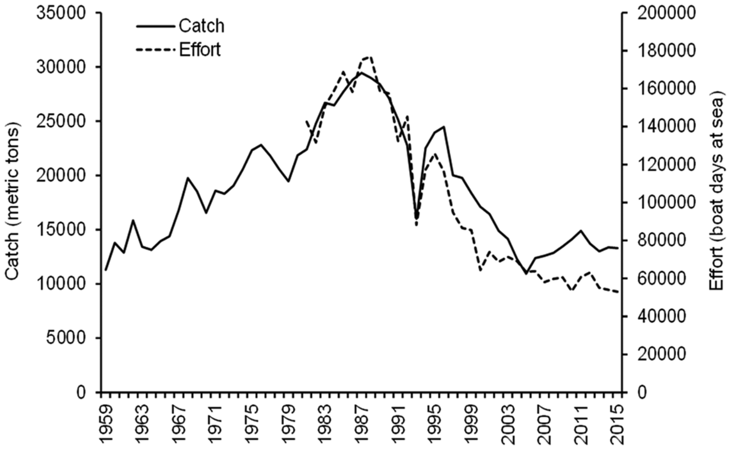

Figure 2. Total finfish catches and total finfish effort in the Cuban fishery (data from Ministry of the Food Industry).

34 species evaluated (Table 2), were selected based on their importance to the fishing enterprises in the coastal waters as reflected by data on catch and effort, and fisheries descriptions obtained from MINAL (data available upon request from the corresponding author). Elasmobranches were not included because a dedicated PSA is underway for these species under the auspices of Cuba's recent National Plan of Action for Sharks (NPOA-Sharks 2015).

Attribute scores were generated by a multi-stakeholder work group involving representatives from CIP, the Cuban National Center for Protected Areas (Centro Nacional de Áreas Protegidas, or CNAP), the national fishing enterprises, and the Environmental Defense Fund (EDF) using a collaborative and consensus-based approach. The core work group was supplemented as needed with experts on particular regions or species. Scores were primarily based on expert opinion in most cases, supplemented where necessary by information derived from the primary literature, gray literature, and online databases (especially FishBase; Froese and Pauly 2016). Expert opinion is increasingly viewed as an appropriate, and even essential, component of ecological modeling and risk analysis, that is most effectively employed with a diverse array of perspectives (Krueger et al. 2012). Stakeholder diversity provided a richer information base from which to draw, and enabled greater scrutiny of individual perspectives and assumptions. Furthermore, our analysis called for scores for 22 attributes for each of 34 species in each of the four management zones, or 2992 individual scores. Each score has a small effect on the outcomes, with the power of the approach lying in the aggregate picture that emerges. Expert opinion enabled us to generate this large number of attribute scores much more efficiently, and for many attributes was the only possible source of information.

For each stock, productivity and susceptibility were estimated from the weighted average of individual scores for 22 attributes in total. Each attribute was scaled from 1 (reflecting low productivity or susceptibility) to 3 (high productivity or susceptibility). We used species-specific information whenever possible. When species-specific information was unavailable, we estimated the attribute value based on information for the closest available congeneric or confamilial taxon from the same geographic

Table 2. Finfish species considered in the present study, including identification (ID) numbers used in Figures 3 and 4, scientific names, common names, and resultant vulnerability category within each of the four Cuban fishery management zones. See Figure 1 for zone locations. L = Low, M = Medium, H = High, VH = Very high.

			Vulnerability category			
ID	Species name	Common name	SE	SW	NW	NE
1	*Harengula jaguana* Poey, 1865	Redear pilchard	L	L	L	L
2	*Harengula clupeola* (Cuvier, 1829)	False herring	L	L	L	L
3	*Opisthonema oglinum* (Lesueur, 1818)	Atlantic thread herring	L	L	L	L
4	*Gerres cinereus* (Walbaum, 1792)	Yellowfin mojarra	L	L	L	L
5	*Diapterus rhombeus* (Cuvier, 1829)	Mojarra	L	L	L	L
6	*Mugil curema* Valenciennes, 1836	White mullet	L	L	L	L
7	*Mugil liza* Valenciennes, 1836	Gray mullet	M	L	L	L
8	*Archosargus rhomboidalis* (Linnaeus, 1758)	Sea bream	L	L	L	L
9	*Haemulon sciurus* (Shaw, 1803)	Blue-striped grunt	M	M	L	M
10	*Selar crumenophthalmus* (Bloch, 1793)	Bigeye scad	L	L	L	L
11	*Caranx ruber* (Bloch, 1793)	Bar jack	L	L	L	L
12	*Caranx latus* Agassiz, 1831	Horse-eyed jack	L	L	L	L
13	*Caranx hippos* (Linnaeus, 1766)	Crevalle jack	L	L	M	L
14	*Trachinotus goodei* Jordan and Evermann, 1896	Permit	L	L	L	L
15	*Lutjanus synagris* (Linneaus, 1758)	Lane snapper	M	L	L	L
16	*Lutjanus apodus* (Walbaum, 1792)	Schoolmaster snapper	L	L	L	L
17	*Lutjanus griseus* (Linnaeus, 1758)	Gray snapper	M	M	H	M
18	*Lutjanus analis* (Cuvier, 1828)	Mutton snapper	L	M	H	H
19	*Ocyurus chrysurus* (Bloch, 1791)	Yellowtail snapper	L	H	M	M
20	*Lutjanus cyanopterus* (Cuvier, 1828)	Cubera snapper	M	M	M	H
21	*Lutjanus jocu* (Bloch and Schneider, 1801)	Dog snapper	L	L	L	L
22	*Acanthurus coeruleus* Bloch and Schneider, 1801	Bluetang	L	L	L	L
23	*Pseudupeneus maculatus* (Bloch, 1793)	Spotted goatfish	L	L	L	L
24	*Scarus vetula* Bloch and Schneider, 1801	Queen parrotfish	L	L	L	L
25	*Balistes vetula* Linnaeus, 1758	Queen triggerfish	L	L	L	L
26	*Holocentrus rufus* (Walbaum, 1792)	Longspine squirrelfish	L	L	L	L
27	*Calamus bajonado* (Bloch and Schneider, 1801)	Jolthead porgy	L	M	M	L
28	*Albula vulpes* (Linnaeus, 1758)	Bonefish	L	L	L	L
29	*Centropomus undecimalis* (Bloch, 1792)	Common snook	L	L	L	L
30	*Megalops atlanticus* Valenciennes, 1847	Tarpon	H	H	VH	VH
31	*Lachnolaimus maximus* (Walbaum, 1792)	Hogfish	M	L	H	L
32	*Scomberomorus cavalla* (Cuvier, 1829)	King mackerel	VH	L	L	M
33	*Epinephelus guttatus* (Linnaeus, 1758)	Red hind	L	L	L	L
34	*Epinephelus striatus* (Bloch, 1792)	Nassau grouper	L	L	M	L

region (ideally Cuba, but otherwise elsewhere in the Caribbean region). Data quality scores reflect confidence in the information utilized, and range from 1 (high quality) to 5 (low quality) for each attribute.

Default assumptions, attribute weightings, and data quality weightings of Patrick et al. (2009) were used throughout the analysis, except where data limitations or the unique characteristics of the fisheries warranted changes. Specifically, for two attributes—population growth rate and biomass of spawners—we used alternative metrics to determine the scores.

Population growth rate, *r*, directly reflects stock productivity, but is also especially difficult to estimate, resulting in wide disparities among studies (Patrick and Cope 2014). Therefore, in the absence of reliable *r* values for our focal species in Cuba, we instead used the intrinsic rebound potential, r_{2M}. This demographic parameter is related to a species' resiliency, and can be estimated accurately using only estimates of age at maturity and natural mortality (Au et al. 2008, 2015). Estimated r_{2M} values for the 34 species in our study ranged from 0.05 to 0.22, with an average of 0.12. We divided this total range into approximately equal sub-ranges for scoring purposes, with $r_{2M} < 0.10$ scored low, $0.10 \leq r_{2M} \leq 0.14$ scored medium, and $r_{2M} > 0.14$ scored high.

Scores for the susceptibility attribute biomass of spawners are typically based on recent estimates of biomass relative to estimates of either unfished biomass, B_0, the maximum biomass in the time series, $B_{\max}$, or the biomass that produces maximum sustainable yield, B_{MSY}. In the absence of biomass estimates and reference points, catch can be a useful, albeit imperfect, proxy for the underlying biomass. Therefore, we scored this attribute based on the most recent estimate of catch, *C*, relative to the maximum catch observed in the period from 1981 to 2015, $C_{\max}$. The same breakpoints used for the biomass attribute in the default PSA methodology were used in our modified catch-based approach, i.e., $C > 40\%\ C_{\max}$ scored low, $25\%\ C_{\max} < C < 40\%\ C_{\max}$ scored medium, and $C < 25\%\ C_{\max}$ scored high. This catch-based approach is susceptible to influences of factors other than biomass on catch, especially markets and management. However, in the Cuban context, these influences are likely to be less given that finfish have received minimal management attention, and commercial and subsistence markets absorb most finfish catch. Ultimately, this attribute, like all others in the analysis, by design has a modest effect on the overall outcomes, so the analysis is robust to violations of this assumption.

Finally, the resulting vulnerability scores were grouped into four categories for comparison and prioritization based on the divisions proposed by Cope et al. (2011): Low (<1.7), Medium (between 1.7 and 1.9), High (between 1.9 and 2.1), and Very High (>2.1).

Results

Total catch, effort, and catch per unit effort (CPUE) vary considerably across Cuba's four management zones (Table 3). All are highest in the southeast zone, while catch and effort are lowest in the northwest zone. Differences in total catch in particular are likely affected in part by the relative size of each zone, and all metrics are likely affected by differences in the composition of fleets in each zone, including vessel and gear characteristics. Effort in the northeast zone approximates that of the southeast zone, but catch is much less. Consequently, CPUE is lowest by far in the northeast zone.

Table 3. Total catch, effort, and catch per unit of effort (CPUE) within each fishery management zone in the Cuban finfish fishery from 2013 to 2015. Data from Ministry of the Food Industry. See Figure 1 for zone locations.

	Zone				
Parameter	SE	SW	NW	NE	Total
Catch (metric tons)	5,822.4	3,498.2	856.4	3,042.2	13,219.2
Effort (boat days at sea)	19,301.0	13,028.0	3,210.0	18,505.0	54,044.0
CPUE (kg/boat day at sea)	302.0	269.0	267.0	164.0	245.0

Table 4. Percentage of total catch within each fishery management zone for major taxonomic groups in the Cuban finfish fishery from 2013 to 2015. Data from Ministry of the Food Industry. See Figure 1 for zone locations.

	Zone				
Taxonomic group	SE	SW	NW	NE	Total
Herrings	24.6	15.2	7.9	9.9	17.6
Mojarras	9.2	0.2	0.0	13.2	6.1
Mullets	1.7	0.0	0.0	4.7	1.4
Grunts	2.1	11.0	3.2	3.7	4.8
Jacks	1.7	3.3	2.0	5.8	2.8
Snappers	8.1	31.5	13.9	10.1	13.6
Total	47.3	61.2	27.0	47.3	46.3

Beyond differences in these aggregate metrics among the four management zones, catch composition also varies considerably (Table 4). Catch in the southeast zone is dominated by herrings, which are an abundant and productive species, and therefore promote high catch and CPUE. However, dominant species alone cannot explain differences in the aggregate metrics, given that mojarras are the dominant species in the northeast zone, and these are also abundant and productive. Notably, the southwest zone is most dependent upon higher trophic level predatory finfish, with the highest proportion of both grunts and snappers in the catch.

Despite these differences in aggregate metrics and catch composition, PSA revealed general similarity among the four management zones. There was no strong evidence for geographic differences in biological or ecological characteristics for any species among regions sufficient to change the productivity attributes, and consequently the overall productivity scores are spatially consistent (Table 5, Fig. 3). Susceptibility scores differed marginally among zones due to factors such as the relative local abundance of different species, proximity of ports to particular habitats and fishing grounds, nearshore infrastructure promoting processing and distribution of certain species, and others. However, these differences were not sufficient to generate large differences in susceptibility. Given the spatial consistency of both productivity and susceptibility scores, overall vulnerability scores showed little differences among zones (Table 5).

Results for individual species generally mirror these similarities among zones (Fig. 3, Table 2). For the majority of species, final vulnerability scores across zones fell into the same category or at most two different but adjacent categories (i.e., Low and Medium, Medium and High, High and Very High). However, the exceptions to this general outcome are important to recognize. Mutton snapper (species no. 18 in Fig. 3) and yellowtail snapper (no. 19) were determined to have low vulnerability in the southeast zone but high vulnerability in at least one of the other zones (see Table 2

Table 5. Mean productivity, susceptibility, and vulnerability scores (SD in parentheses) among 34 finfish species within each of the four Cuba fishery management zones. See Figure 1 for zone locations.

Zone	Productivity	Susceptibility	Vulnerability
SE	2.29 (0.38)	2.27 (0.37)	1.50 (0.34)
SW	2.29 (0.38)	2.18 (0.39)	1.43 (0.36)
NW	2.29 (0.38)	2.28 (0.31)	1.51 (0.33)
NE	2.29 (0.38)	2.21 (0.34)	1.45 (0.34)

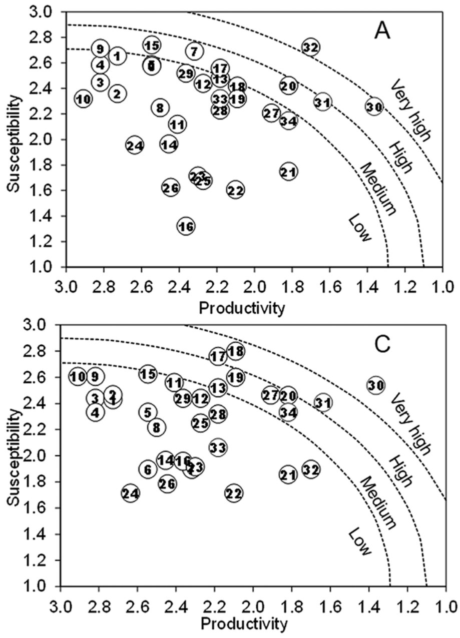

Figure 3. Productivity and susceptibility scores for 34 finfish species within each of the four Cuban fishery management zones, including the (A) southeast zone, (B) southwest zone, (C) northwest zone, and (D) northeast zone. Dashed lines represent breakpoints between the vulnerability categories. See Table 2 for species identification numbers.

for species names and authorities). Conversely, king mackerel (no. 32) has very high vulnerability in the southeast zone, but low to medium vulnerability in all others. Similarly, hogfish (no. 31) has low to medium vulnerability in all zones but the northwest, where its vulnerability is high.

The majority of vulnerability scores across all zones fell into the low category, with very few in the high and very high categories (Table 2, Fig. 3). However, a PSA is intended to provide a relative, rather than absolute, evaluation of risk. Furthermore, the biological vulnerability of a stock does not necessarily convey the socioeconomic vulnerability of the fishing communities that depend upon it. Evaluation of socioeconomic vulnerability is a complex and evolving enterprise, requiring specialized expertise, data, and tools (e.g., McLaughlin et al. 2002). To provide some initial insights, we examined PSA results relative to the importance of each species in each zone as reflected by the proportion of each species in that zone's catch. Catch composition varies more widely among species than vulnerability scores, with a small number of species comprising the majority of the catch in each zone. The fishing portfolio is most diversified in the northeast zone, where no species made up >10% of the catch (Fig. 4D). In contrast, a single species comprises >20% of the catch in each of the southeast and southwest zones (Atlantic thread herring and lane snapper, respectively; Fig. 4A, B). The northwest zone lies in between these divergent trends, with fewer species dominating the catch than the northeast zone, but none comprising >8% (Fig. 4C, D).

Vulnerability of a stock shows, at best, a weak relationship with the proportion of the catch it comprises in all four management zones (Fig. 4). The stock with highest vulnerability in each zone is not the stock accounting for the majority of the catch.

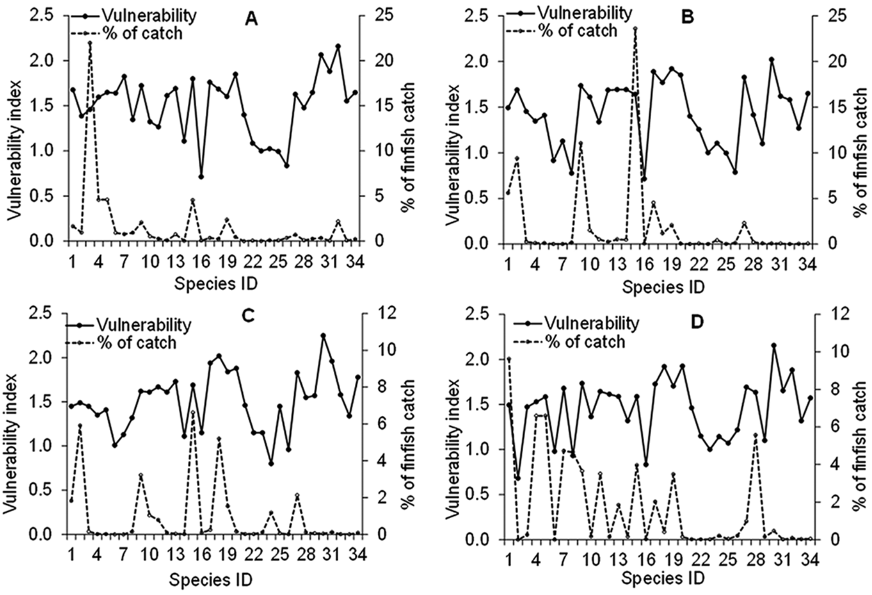

Figure 4. Vulnerability indices and percentage of the total finfish catch for 34 species within each of the four Cuban fishery management zones, including the (A) southeast zone, (B) southwest zone, (C) northwest zone, and (D) northeast zone. See Table 2 for species identification numbers.

On the other hand, these attributes certainly do not show an inverse relationship. Stocks that are more prominent in the catch are more likely to have higher vulnerability scores, but the relationship is not strong.

The distribution of stocks among vulnerability categories within each zone relative to catch composition suggests that the fishing fleet is most reliant on low vulnerability stocks (Table 6). Stocks with low vulnerability represent 73%–80% of those considered within each zone, and account for 21%–50% of the catch. Fishing communities in the northwest zone appear to be the most at risk, given that there is a greater proportion of stocks in the high and very high categories in that zone (11.7%), and nearly the greatest proportion of catch in those categories as well (5.7%). Perhaps more importantly, the 34 species that we considered collectively account for the lowest overall proportion of the catch in the northwest zone (31.2%), which means that we currently lack insights into the vulnerability of more than two-thirds of the species comprising the catch in that narrow zone, where small tunas and rays are the main fishery resources. This uncertainty introduces a different type of biological and socio-economic vulnerability.

Discussion

Vulnerability scores for the 34 finfish species considered were generally low across the four management zones, but this is a relative rather than absolute metric and does not necessarily mean that the stocks are not presently overfished. Stock status for most finfish species harvested in Cuban waters is unknown. Patrick et al. (2009) examined the distribution of stock status among vulnerability scores for fish stocks in the US. They found that, although high vulnerability stocks were more likely to be

Table 6. Percentage of 34 finfish species within each vulnerability category by, and percentage of the total finfish catch accounted for by those species within each Cuban fishery management zone from 2013 to 2015. Catch data from Ministry of the Food Industry. See Figure 1 for zone locations.

	SE		SW		NW		NE	
Category	Species	Catch	Species	Catch	Species	Catch	Species	Catch
Low	76.6	42.1	79.4	43.6	73.6	21.6	79.4	49.5
Medium	17.6	8.3	14.7	19.1	14.7	3.9	11.8	9.2
High	2.9	0.4	5.9	2.1	8.8	5.6	5.9	0.6
Very high	2.9	2.2	0.0	0.0	2.9	0.1	2.9	0.5
Total	100.0	53.0	100.0	64.8	100.0	31.2	100.0	59.8

overfished and low vulnerability stocks were less likely to be overfished, several high vulnerability stocks were not overfished and several low vulnerability stocks were overfished. The overall prevalence of overfished stocks in Cuba is likely to be higher than in the US due to the additional challenges facing fisheries in the developing tropics (Prince 2003), especially those with complex spatial structure (Kritzer and Liu 2013) and lacking stock assessments (Costello et al. 2012).

Our analysis involved at least two assumptions, the validity of which is unclear. We assumed that the boundaries of Cuba's fishery management zones approximate stock boundaries for the species considered, and that catch is a reasonable proxy for abundance or biomass. The assumption about stock boundaries is probably the more untenable of the two. However, the results revealed little spatial variation in vulnerability indices, which means that lower spatial resolution (e.g., north coast vs south coast, or single vulnerability estimates at the national scale) would have produced a similar relative picture. Assumptions about stock boundaries will have greater significance as stock assessments are conducted for individual species based on the prioritization enabled herein.

The extent to which catch reflects abundance is a topic of ongoing debate in fisheries science (see, e.g., Pauly et al. 2013). Generally, catch is likely to reflect abundance if fishing effort is not significantly altered by management or markets, or availability of fish to the fishing fleet is not significantly affected by environmental factors that shape their distribution and behavior. In Cuba, management of finfish to date has been minimal, so constraints on fishing behavior have likewise been minimal. Also, the demand for seafood is not met by the domestic supply, which means all domestic catch is readily absorbed by subsistence and tourism markets, and seafood imports are needed to fill unmet demand. Therefore, neither of these factors are likely to decouple the relationship. As discussed below, a variety of environmental impacts might have altered the distribution and behavior of some species over time, so this could be a more important factor. However, it is unlikely that the changes have been so profound as to result in fishers being fundamentally unable to locate target species. Furthermore, given that a PSA produces relative indices and rankings, violation of this assumption would have to be of a drastically different nature for different species. Even if that unlikely situation is the reality, this assumption affects only one among 22 attributes that collectively determine the vulnerability score for a given species, which means it affects <5% of that score. Therefore, the assumption that catch is a useful proxy for abundance is reasonable in this context, and the overall analysis is robust to it being invalid.

Although overfishing is very likely to be one of the factors contributing to currently-low catches in Cuba, not all of the observed changes in the fishery over time can be attributed to this single factor. Non-fishing impacts are certainly having an effect as well, and some of these are probably irreversible (Baisre 2000). Habitat degradation has occurred in many nearshore areas in recent decades (Claro et al. 2009). For example, runoff of fresh water and nutrients is unnaturally low because most of the major rivers have been dammed. Although excessively high inputs of fresh water and nutrients can adversely lower salinity levels and contribute to hypoxia (Cowan 2009), excessively low inputs can alter water quality and biological dynamics as well (Begon et al. 2006). Damming has increased salinity over large areas of shallow water and brackish lagoons along the Cuban coast where recruitment and nursery areas of most species occur (Claro et al. 2001b, Baisre and Arboleya 2006). Puga et al. (2013) concluded that the degradation of coastal habitats in Cuba must be taken into account in stock assessment and development of management strategies. The likelihood of overfishing combined with detrimental non-fishing impacts has resulted in a drastic reduction in effort in Cuban fisheries. In 1988, the commercial finfish fleet was composed of around 840 vessels, but by 1998 this number had decreased to 400 (Valle et al. 2011).

Currently, one of the highest value commercial fisheries targets lane snapper (9.1% of the total national finfish catch), primarily in the southwest zone (23.6%). Over the last decade, lane snapper stocks have continued to decline despite implementation of additional fisheries regulations. Habitat degradation may have influenced this species through hyper-salinization of inner lagoons, hurricane damage to *Thalassia* beds, and changes in water circulation in coastal areas (Claro et al. 2009).

In fact, the snapper complex as a whole was historically the principal finfish fishery group in Cuba, comprising 30% of total finfish catch until 1975, 22% from 1976 to 1980, and 19% from 1986 to 1990 (Claro et al. 2001a, 2009). At present, its importance has substantially diminished, with the group now representing <14% of the total finfish catch. In addition to high fishing pressure, degradation of coral reefs as a result of coral bleaching and algal overgrowth during several ENSO events may have negatively affected aspects of the life cycle of these reef-associated species (Claro et al. 2009).

The declining importance of higher trophic level species such as snappers has been accompanied by increasing importance of lower value and higher productivity species such as herrings and mojarras. Herrings comprise nearly 18% of the national finfish catch, with Atlantic thread herring representing 22% of finfish catch in the southeast zone. Similarly, mojarras comprise 13% of the catch in the northeast zone and 9% of the catch in the southeast zone. These species rely on estuaries and coastal lagoons, habitats that are affected by changes in salinity, nutrient inputs, and other attributes, but are not as reliant upon the degraded biotic habitats utilized by snappers and other demersal species.

The largest volume of finfish catch in the mid-1980s was from the northeast zone, comprising 30%–35% of the national total (Claro et al. 2001a). However, since 1982, the ecology of this zone has been altered significantly by construction of multiple causeways connecting the small keys with the Cuban mainland. Consequently, the majority of catch now derives from the southeast zone, with 44% of the national total. High contemporary catch and CPUE in the southeast zone might be attributable in part to the presence of the Gardens of the Queen Marine Park, the largest and most well-resourced MPA in Cuba. Investment in this MPA has generated higher levels of monitoring and enforcement, ecological recovery, and fishery spillover in this management zone (Kritzer et al. 2014, Pina-Amargós et al. 2015).

These shifting patterns of catch volume by zone, species' prominence in the catch, and habitat conditions underscore the value of a tool such as PSA. Catch composition alone does not sufficiently reflect prospective importance of any particular species. Those that were historically important, but are not currently, might have recovery potential with the right scientific and management action, and therefore might increase in socioeconomic value. Those that have not been important might one day represent a greater proportion of the catch if market conditions change or depletion of other species causes fishers to seek alternative targets. PSA enables development of a strategy for assessing all species of interest over time, providing the knowledge base needed for effective management. New species will need to be added to future PSA studies in Cuba given that many species caught in the fisheries are not represented in our analysis. This is especially important given the dynamic spatial and temporal differences observed in these fisheries. Strategic use and expansion of PSA results can help to recover overfished species, responsibly increase harvest of those that are underutilized, and guard against future depletion of all resources to promote ecological and socioeconomic stability.

The paucity of information on the status of finfish stocks in nearshore waters across the developing tropics (Costello et al. 2012), conditions that often motivate application of PSA as a prioritization tool, make it difficult to place the status of Cuban finfish fisheries in a regional or global context. Regardless, Cuba's own success with management of high-value invertebrate fisheries (Baisre 2006) provides a roadmap for how to improve management of finfish resources. Management of invertebrate fisheries in Cuba is based on regular scientific assessments, which can be achieved for the larger number of finfish species by utilizing the growing toolkit of data-limited analytical approaches (see Honey et al. 2010). Furthermore, invertebrate fisheries in Cuba are managed by a combination of input and output controls, as well as allocation of exclusive spatial access to fishing grounds among the state-owned fishing enterprises alongside Cuba's extensive MPA network. Accumulating global experience shows that science-based management, spatial allocation of access, and MPAs together constitute an effective approach to managing nearshore fisheries in developing countries (Barner et al. 2015). Such an approach could potentially be replicated for the non-state-owned fleets that harvest finfish in Cuba by capitalizing on and supporting social cohesion and leadership (Gutiérrez et al. 2011).

PSA provides a useful starting point for prioritizing data collection and management when robust information on stock abundance, catch levels, or other traditional fisheries metrics are unavailable. It enables risk-based prioritization of research and management efforts using a transparent and broadly applicable framework. The PSA described herein, focused on 136 targeted finfish stocks across four management zones in Cuba, provides MINAL with a tool for improving monitoring, assessment and management of finfish fisheries, and development of new fisheries policies. PSA provides insight into which species are in greatest need of measures to prevent overfishing through a variety of harvest controls (Liu et al. 2016) and other measures. The results can also contribute to developing more sustainable supplies of fish for food security and economic growth in Cuba.

Acknowledgments

Funding for this study was provided by the European Union in support of the SOS Pesca project, a partnership among Cooperation for Development of Emergent Countries (COSPE), World Wildlife Fund-Netherlands, Cuba's CNAP, and other Cuban institutions. Additional funding to EDF was provided by the MacArthur Foundation and the Ford Foundation. R Fujita, T Gedamke, W Batista, V Miller, P Pattison, and D Whittle all provided training, advice, and other support without which this study would not have been possible. Finally, we thank the guest editors for inviting this contribution.

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