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SHORT COMMUNICATION

A PRELIMINARY INVESTIGATION OF ADHERENCE TO SHELL LENGTH REGULATIONS AND ADAPTIVE CAPACITY OF THE TURNEFFE ATOLL QUEEN CONCH (*ALIGER GIGAS*) FISHERY, BELIZE

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KEY WORDS: Community resilience, Caribbean, overfishing, artisanal fishery, shell lip thickness

INTRODUCTION

Queen conch (*Aliger gigas,* formerly: *Strombus gigas, Lobatus gigas*) and spiny lobster (*Panulirus argus*), henceforth "conch" and "lobster," are the most economically important fisheries in the Caribbean (Theile 2001). In Belize, fishing pressure on conch has increased since the 1970s (Theile 2001). To improve the fishery's sustainability, the Belize Fisheries Department has implemented a seasonal quota (calculated using the Maximum Sustainable Yield model), established protected areas, mandated gear restrictions, and prohibited harvest from 1 July – 30 September. If the annual quota is reached before 1 July the fishery can be prematurely closed (Fisheries Act 210 2003). Early closures occurred continuously from 2019—2024. Current regulations state that harvested conch must have shell lengths (SL) >17.78 cm (7 in), a "market clean" (shell, operculum and gonads removed) weight of 85 g (3 oz) and a fully processed (fillet) weight <78 g (2.75 oz). However, SL is an unreliable metric of adult (lipped) conch maturity, whereas lip thickness (LT) is a more reliable indicator (Stoner et al. 2012a, Foley and Takahashi 2017, Boman et al. 2018, Stoner et al. 2019). There is currently no LT harvest criteria in Belize. We hypothesize that current SL standards without LT regulation contribute to the harvest of sub—adult, lipped conch (Theile 2001, Tewfik et al. 2019).

In addition to the harvesting of juveniles and sub—adults, the Belizean conch fishery faces increasingly frequent external challenges. For example, the recent COVID—19 pandemic rapidly altered the economics of small—scale fishing communities, including those of the Caribbean, and has been correlated with increased harvest of illegal—size conch (Bennett et. al. 2020, Higgs 2021). Natural hazards including hurricanes—which are predicted to increase in frequency and severity as a result of climate change—threaten the fishery by causing larval mortality, disrupting juvenile habitat, burying conch, and damaging fishing gear (Karlsson and McLean 2020, Stoner and Appeldoorn 2021). In the midst of increasing stress, there is an urgent need to better understand the dynamics of Caribbean small—scale conch fisheries to augment resilience.

Adaptive capacity (AC) is defined as the ability to "anticipate, respond to, and recover from change" (Cinner et al. 2015). The AC is a component of resilience that can be used to assess a community's ability to react to and recover from stress, and identify pathways for adaptation (Adger and Vincent 2005, Nelson et al. 2007). Small—scale fisheries can adapt through increased access to assets, institutional support, diversity and flexibility, learning and knowledge, and natural capital (Green et al. 2021). An AC is therefore derived from a fisher's unique environment and community. Presently, there is no standardized method to assess AC, despite attempts to standardize methodology (Cinner et al. 2011, Moreno—Sánchez and Maldonado 2013, Maldonado and Moreno—Sánchez 2014).

This preliminary study examines the resilience of the conch fishery in Turneffe Atoll (henceforth "the atoll"), Belize (Figure 1), and general adherence to national SL regulations. The objectives of this study were to: 1) estimate adherence to SL regulations and the efficacy of

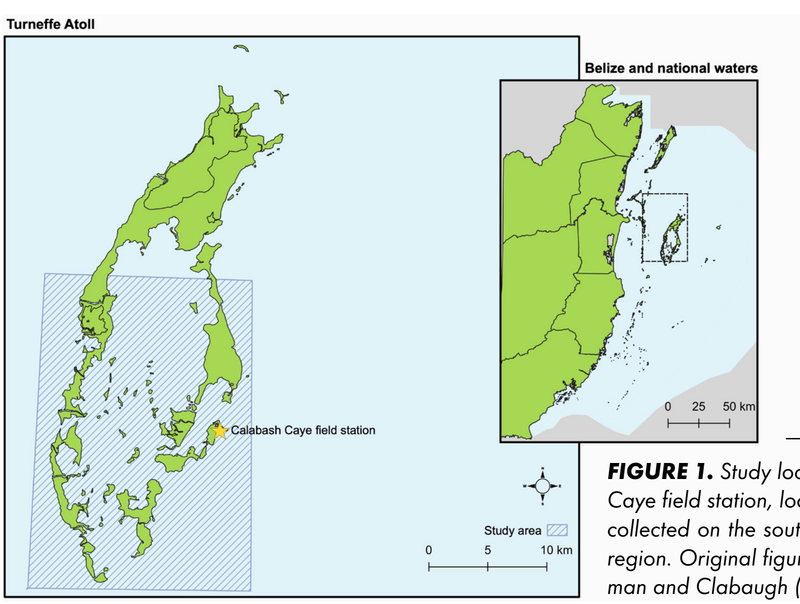

FIGURE 1. Study location at Turneffe Atoll, Belize. Researchers were based in Calabash Caye field station, located on the southeast of the atoll. All shell and interview data were collected on the south end of the atoll, in the study area indicated by the blue hatched region. Original figure created in QGIS (v. 3.16.16) with open source data from Meerman and Clabaugh (2017).

regulations to protect sub—adult lipped conch, 2) identify potential threats to the fishery's resilience as perceived by fishers, and 3) provide an initial assessment of the AC of the local conch fishing community.

Materials and Methods

Adherence to shell length regulations

We measured conch shells discarded after harvest, "knocked shells," throughout the atoll (n = 150) to assess adherence to conch fishing regulations in the recent past. Knocked shells were selected via convenience sampling, with inclusion based on visual evidence of harvest as inferred from the presence of 1—2 holes along the spire of the shell, noted by local fishers and key informants as standard technique for removing meat from shells. Shells were frequently found in piles of multiple discarded shells, termed "shell graveyards," which were found both on land (landfill; n = 41) and underwater (snorkel; n = 109). Maturity was determined using a 10 mm LT threshold (Tewfik et al. 2019). Length (SL) was measured using a ruler from the furthest most point of the spire to the end of the body, and lip thickness (LT) was measured using a caliper at the widest point of the lip (Figure 2A). Both landfill and snorkel shells with measurable SL and LT were used to calculate the correlation between SL and LT (combined n = 150).

To assess adherence to SL regulations in the recent past, a qualitative metric to determine relative time since harvest was implemented. We estimated this relative classification based on the amount of epibiotic growth present on knocked shells. For this analysis, only shells collected via snorkeling (n = 109) were used to reduce biases introduced by different relative aging appearances on land and underwater. Epibiota accumulate over time on marine organisms (Botton and Ropes 1988, Jennings and Steinberg 1997, Dick et al. 1998). Using this principle, we employed an age classification system outlined in Figure 2B to categorize all snorkel shells as "new," "medium," or "old" according to the amount of epibiotic growth present on the inner lip. This system provides a relative time since harvest classification: the inner shell surface is kept clean by the conch while alive, therefore newly knocked shells present with little epibiotic growth and appear pink or cream in color. As epibiotic growth increases, natural shell color simultaneously deteriorates.

All statistical analyses were conducted in R (v.4.3.1). Shapiro—Wilk tests were used to test for normality. For SL and LT correlation analysis, Kendall's correlation (KC) was used due to repeated ranks and non—parametric data structure. For comparison of SL and LT among age groups, a Kruskal—Wallis (KW) test was used due to the non—parametric data structure. A threshold level of 5% (α = 0.05) was used for statistical significance. R Markdown documentation of all analyses is publicly available on Github (https://github.com/elsamkbrenner/conch).

Adaptive capacity

We measured AC using methods developed by Cinner et al. (2013), modified to reflect factors pertinent to Turneffe Atoll. We conducted 12 semi—structured interviews with fishers from 9 separate artisanal fishing units (groups of collaborating fishers, each consisting of 3—12 individuals). In cases where multiple interviewees came from the same fishing unit, interviews were conducted concurrently. An additional 5 interviews were conducted with key informants from the Turneffe Atoll Sustainability Association (TASA) and the Calabash Caye Field Station (Supplemental Table S1). Interviews were conducted by the authors with assistance from Calabash Caye Field Sta-

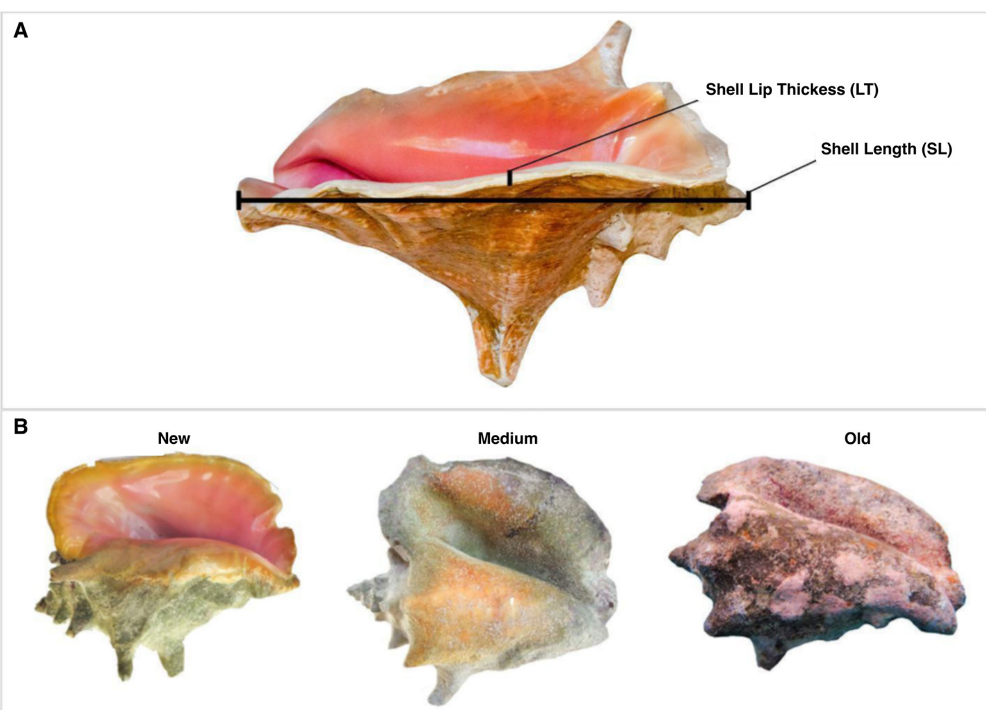

FIGURE 2. *Illustrations of metrics used to quantify size and age of Queen Conch shells. A. Shell Length (SL) (black horizontal line) and lip thickness (LT) (black vertical line). B. Knocked shells were assigned a relative time–since–harvest classification using a "new," "medium," "old" scale, differentiated by the amount of epibiotic growth present on the inner lip. New shells exhibited no epibiotic growth on the inner lip nor discoloration; medium shells exhibited some epibiotic growth on the inner lip and faded coloration, but remained smooth to the touch; old shells had inner lips completely covered in epibiotic growth, and a palpable bumpy texture. Photos by Elsa Brenner and Joanna Lee.*

tion staff. Fishers were invited for interviews while fishing in the southeast region of the atoll, over a 2—week period in November 2019. Interviews were conducted in English, with translation assistance from Calabash Caye Field staff when necessary. Interviews were transcribed in the field, digitized and independently coded by 2 members of the research team, and compared for consistency.

Adaptive Capacity (AC) of fishers (n = 12 interviews) was assessed based on a composite score of 7 categories: catch diversity, ecological knowledge, equipment, years of experience, generational knowledge, range, and seasonality. Categories were structured based on those used in Cinner et al. (2013), and were chosen based on key themes that emerged from interviews. Each category was scored on a scale of 1—3; such that 1 was least adaptable and 3 was most adaptable (Figure 3A). Mean scores are reported. Score breakdowns were based on the following classifications: catch diversity (1 = only conch, 2 = conch and one other fishery, 3 = 3 or more fisheries); ecological knowledge (1 = interview offered little to no ecological information; 2= interviewee offered limited ecological information; 3 = interviewee readily offered ample ecological information to support their observations); equipment (1 = little—no equipment, i.e. snorkeling to retrieve conch, 2 = limited equipment, i.e. a hook—stick for lobster, 3 = complex or specialized equipment, i.e. lobster traps, which require regular repair and maintenance); years of experience (1 = <10 years of fishing experience, 2 = 10—20 years of fishing experience, 3 = >20 years of fishing experience); generational knowledge (1 = all individuals in the fishing unit are of one, younger generation; 2 = all individuals in the fishing unit are of one, older generation; 3 = 2 or more generations are active in the fishing unit); range (1 = camp based; 2 = small boat; 3 = sailboat); seasonality (1 = fished the entire year; 2 = fished during only certain fishing seasons, used the off season(s) for preparatory work; 3 = fished during only certain fishing seasons, offseason as vacation or free—time to pursue other professions). Interview results are discussed qualitatively, to provide a preliminary overview of perceived challenges by the fishers operating out of the atoll.

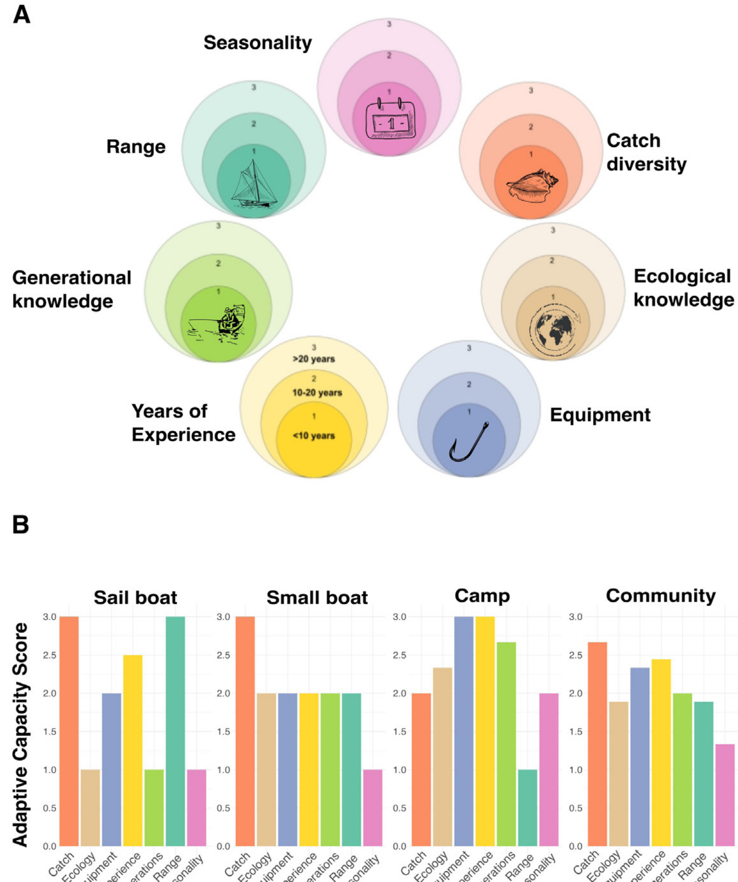

FIGURE 3. *Assessments of Adaptive Capacity of fishing units. A. Seven categories of Adaptive Capacity, each scored from 1—3, such that a score of 1 was least adaptable and a score of 3 was most adaptable. Assessments were based on a composite score of these categories. B. Mean scores from the 3 types of fishing units interviewed—sailboat (n = 2), small boat (n = 3) and camp (n = 7), along with the community mean score for all fishing units interviewed. Due to small sample sizes, variance is not included.*

Results and Discussion

Our preliminary findings indicate that the majority (87.4%) of harvested conch (n = 150) measured longer than the legal minimum (average SL 20.18 ± 2.41 cm), indicating relatively high adherence to existing regulations. We found no significant correlation between SL and LT (KC: τ= 0.056, p = 0.35), which supports the recommendation by Stoner et al. (2012a) to transition away from SL harvest criteria. For knocked shells, 73.3% fell below the 10 mm LT maturity threshold (average LT 7.17 ± 4.71 mm) reported by Tewfik et al. (2019), suggesting a high rate of sub—adult conch harvest. We found no differences in SL (KW: p = 0.70, x^2_3 = 1.42) nor LT (KW: p = 0.15, x^2_3 = 5.30) between relative time since harvest categories, indicating consistent selection criteria by fishers over time. Our results, though preliminary, are in alignment with other larger studies and support the notion that current SL—based size regulations result in legal harvest of not only juveniles but also sub—adult lipped conch. In addition to reducing spawning stock biomass, this harvest of sub—adult conch may be causing fishery—induced selection pressure towards shorter length conch (Tewfik et al. 2019, Stoner et al. 2012b, 2012c).

Interview analyses suggest that both fishers and key informants perceive the fishery as in decline due to overfishing. The majority of fishers and all key informants (86% of all interviewees) identified overfishing as the primary perceived threat to the conch fishery. Other perceived threats included illegal fishing (44%), climate change (33%), and insufficient regulations (11%). The most common concern from fishers was that enforcement was not present when illicit fishers were active (33% of fishers). All key informants, who work closely with enforcement, echoed this concern and identified the need for better enforcement; though all key informants commented that they did not believe that additional enforcement would decrease the prevalence of illegal fishing. Additional research is needed to understand what existing dynamics are leading to these perceived weaknesses of the current enforcement system. Understanding perceived weaknesses is a valuable step towards increasing trust between authorities and fishers. Trust in turn corresponds with the exchange of knowledge, skills, and techniques among parties, which leads to more robust and adaptive fishing communities (Green et al. 2021).

On average, fishers scored the lowest in seasonality (mean 1.3), indicating that under current management practices, they are unable to devote additional time to fishing or acquiring revenue through alternative means (Figure 3B). Fishers who work year—round do not have the option to use the off—season to maintain their equipment, placing them at increased risk of economic strain from declining fisheries, overfishing, and economic or environmental disruptions. In contrast, fishers tended to score the highest in catch diversity (mean 2.7, Figure 3B). Most participating fishers relied on 3 or more fisheries for their livelihood, often including conch, lobster, and a variety of finfish. This indicates that catch diversification and flexibility are 2 existing strengths of the community, as both have been shown to increase adaptability (Karlsson and McLean 2020). Functionally, catch diversity acts as a form of insurance for artisanal fishers, increasing harvest capability and decreasing the risk of a substantial loss of income in the case of a single fishery's closure or decline (Cline et al. 2017). However, it should be noted that catch diversification requires purchasing new equipment and redistributing effort. Of interviewed fishers, years of fishing experience ranged from 3—50 years (mean 24.8 years); and 58% (n = 7 interviews) operated out of camps, 25% (n = 3) from sailboats, and 17% (n = 2) from small boats. Camp and small boat fishers have a more limited range (Figure 3B); if scarcity were to necessitate fishing over larger areas, they may be unable to adapt effectively. This represents one weakness of the fishery, as mobility and flexibility tend to increase AC (Karlsson and McLean 2020). With each choice, fishers have the potential to change AC; what drives these choices and how fishers balance their tradeoffs are interesting directions for further study and would greatly improve our understanding of the atoll's AC.

Limitations to this preliminary study include opportunistic selection of knocked shells and a low number of interviews. Sample sizes were confined due to the constraints of university course timing and the inability to continue fieldwork in subsequent years due to COVID—19 travel restrictions. Results should be considered as a preliminary report, and further research is vital to understand the complex dynamics of the atoll's artisanal conch fishery. In particular, the interview sample size provided insufficient data for meaningful statistical analysis. Despite these logistical limitations, this research provides value in identifying essential themes and trends that future studies can build on, particularly in light of potential COVID—19 effects on the fishery subsequent to this study. Furthermore, the qualitative interview data presented here contextualizes fishers' perceptions of overfishing and inefficient enforcement as significant threats to the conch fishery.

Future concerns for the fishery include a projected increase in hurricane frequency and severity, and projected decline of other economically important fisheries, including lobster (Adger et al. 2005, Huitric 2005, Karlsson and McLean 2020). Relationships among fishers and management agencies are critical to developing sustainable management strategies in light of these projected challenges. The involvement and agency of fishers is critical (Green et al. 2021). Our analyses suggest that fishers adhere to current SL regulations, but the regulations lead to the legal harvest of sub—adult conch. We recommend the addition of LT to harvest criteria as a means to protect both the conch population and the livelihoods of the Turneffe fishing community.

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