Evaluation of the Local Trends in the Spatial and Temporal Variation of Hogfish – *Lachnolaimus maximus*, in South Caicos, Turks and Caicos Islands, BWIs

Evaluación de las Tendencias Locales en la Variación Espacial y Temporal de Hogfish - *Lachnolaimus maximus*, en South Caicos, Islas Turcas y Caicos, BWI

Évaluation des Tendances Locales dans la Variation Spatiale et Temporelle de Hogfish - *Lachnolaimus maximus*, dans le Sud Caïques, Îles Turques et Caïques, BWIs

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ABSTRACT

In the Turks and Caicos Islands, *Lachnolaimus maximus* (*L. maximus*, hogfish) is a highly valuable species, important for domestic consumption by both local communities and visiting tourists. Fisher-dependent measurements were used to assess spatial and temporal variation in the total length of hogfish landed on the island of South Caicos between 2004 and 2017. It was determined that 48.5% of the individuals sampled were below the average length of hogfish at sexual transition, indicating potential dangerous fishing patterns in the Turks and Caicos *L. maximus* fishery. Oscillating patterns in median total length over time from 2005 to 2012 suggest a 3 - 4 year size cycle, but this pattern has not been observed since 2014. Two study locations, on the northeast side of the Caicos bank, indicate a significant trend of increasing size, as well as an increase in fishing activity, which suggest increased fishing pressures to those areas. Possible impacts of intense fishing of larger individuals include reduced male populations, which could alter recruitment to the reproductive stock. This study illustrates the ability of total length measurements to detect subtle spatial differences and supports the argument that data-poor fisheries stand to benefit greatly from simplified monitoring techniques; and emphasizes the importance of monitoring and management of the *L. maximus* in the Turks and Caicos Islands.

KEYWORDS*:* Hogfish, geospatial, finfish, temporal, protogynous, fisheries, South Caicos

INTRODUCTION

Sustainability of small-scale fisheries has gained global attention, as demand for protein sources increase alongside reports of reef degradation (Worm 2009, Pauly and Zeller 2016). Without the resources to conduct full-scale stock assessments, these small-scale fisheries are often data-poor and lack a basis for evaluating their sustainability objectives (Mahon 1997). By the time management of a growing fishery is addressed, fish stocks are often beyond self-repair, affecting the livelihoods of the communities who depend on them (Sadovy 2001). This depletion of stocks beyond regeneration is known as overfishing (Froese 2001).

With the use of more simplified models that rely on length-based indicators from landed catch, data accessibility and monitoring of small-scale fisheries is more plausible (Kantoussan et al. 2009), and have produced mortality measurement similar to catch-and-effort time series data (Ault et al. 2005). These length-based indicators can indicate whether a fishery is undergoing sustainable rates of exploitation by directly reflecting alterations to population structure related to fishing mortality (Quinn 2003). Although length in the exploited phase is increasingly used as a temporal monitoring tool for small -scale fisheries (Ault et al. 2005, Ault et al 2008, Babcock et al 2013, Lambert et al. 2009), it is rarely used to assess size structure on fine spatial scales (Canales et al. 2016).

Commercial catches of various fisheries throughout the Caribbean and western Atlantic have been reported to be in decline. The Turks and Caicos Islands (TCI) is an example of small-scale fisheries with limited data for assessment of the declining fisheries. However, the TCI has collected considerable information on its two most profitable fisheries of queen conch (*Lobatus gigas*) and Caribbean spiny lobster (*Panulirus argus*) that have had variable catches over the last decade (Lockhart et al. 2007, Ulman et al. 2016). In 2005, the TCI government completed a fisheries management plan (TCIG 2005) to assist with the direction of the fisheries for sustainable catch. One of the initiatives was to diversify from the two high priority fisheries into the presumed under-exploited fin-fish fisheries. However, with a small-scale fishery, both limited capacity and finance for the government has restricted proper data collection and it has therefore proven difficult to assess the fin-fish fishery. The hogfish, *Lachnolaimus maximus*, fishery is particularly understudied, despite the fact that it is one of the five most valuable reef fish species in the Turks and Caicos Islands and is a common source of local protein (Ulman et al. 2016).

L. maximus are the largest tropical Atlantic wrasse (Randall, 1967) in the family Labridae (Choat et al., 2010, Humann & DeLoach, 2011). As a diurnal (Knight et al. 2006), monadric, protogynous hermaphroditic species (McBride and Johnson 2007), meaning that they change chronologically from female to the terminal male phase as they mature (McBride et al. 2007), they can grow to 3 ft (91.4 cm) in length as adults (Humann and DeLoach 2011), with males being significantly larger than females of the same age class (Muñoz et al. 2010, Choat et al. 2010). *L. maximus* mate with a single male controlling a harem of up to 15 females (Sadovy 2001). The change of sex most often occurs once they have reached a length of 30 - 40 cm or an age of 3 - 5 years (McBride et al. 2007). *L. maximus* distributions range from North

Carolina to Brazil, including Bermuda and the Gulf of Mexico, in waters from 3 - 40 meters in depth (Choat et al. 2010, Bunkley-Williams and Williams 1999, Humann and DeLoach 2011). Adults are traditionally found in open areas of the sea bottom in the vicinity of reefs (Randall 1967). Habitat selection can range from macroalgae microhabitats to more preferred sandy coral rubble and gorgonian habitats (Muñoz et al. 2010). This preference may be due to their diet relying largely on benthic organisms such as pelecypods (bivalves) and gastropods, with smaller amounts of other mollusks, echinoderms, and small crustaceans (Randall 1967, Muñoz et al. 2010).

L. maximus are a significant fisheries fish throughout their range (Bunkley-Williams and Williams 1999), and in response populations are decreasing globally (Choat et al. 2010). This decline has reached the point that the species is classified as 'Vulnerable' on the International Union for the Conservation of Nature's red list of endangered species (Choat et al. 2010, Ulman et al. 2016). Based on the classification, determining the current exploitation is necessary, and studies such as Ault et al. (2005) have examined how average length (Lbar) reflects the rate of fishing exploitation. Studies such as Ehrhardt and Ault (1992) and Quinn and Deriso (1999) have indicated that Lbar estimators for mortality are not biased with a constant recruitment to the stock. In an effort to prevent overharvesting of young hogfish, Florida's hogfish fishery recently increased its minimum size restrictions from 12 inches (30.5 cm) to 14 inches (35.5 cm) (GMFMC 2016). This increase aligns better with the reproductive traits of *L. maximus*. According to Ault et al. (2005) study of the Florida Keys, the Lbar method for estimating total mortality was relatively robust for assessing exploitations, which may prove beneficial in data limited situations. The goal of most fisheries management regulations is to protect breeding populations until they have had a chance to reproduce, often indicated by the average length at sexual maturity L_m. For *L. maximus*, the conservation equivalent is waiting for females to have the chance to become males and subsequently breed with available females (McBride et al. 2001), which occurs at ~ 35 cm and is referred to as $L_{sexual\ transition}$ (McBride et al. 2007).

The Ault et al. (2005) study based findings on a relative non-select effort of hook and line. Since *L. maximus* feed on benthic organisms, they are less susceptible to hook and line fishing. Hence, the primary mode of capture is selective spear-fishing (Collins and McBride 2011, Tupper and Rudd 2002). The selective capture of megaspawners, the largest (most fecund) individuals in a population, *L. maximus*, can negatively influence the reproductive dynamics of a population by changing the size structure and sex ratios, thereby decreasing opportunities for sexual selection (Kantoussan, J. et al. 2009, Bianchi 2000, Haedrich and Barnes 1997, Kendall and Quinn 2013, McBride and Richardson 2007, Shepherd et al. 2010). Although the removal of a male can induce a female within a harem to change sex, this adaptive capacity does not fully compensate for the removal of large individuals (most often males), because sex changes takes several months to complete (McBride et al. 2007).

As a restrictive effort measure, the restricted free-diving range of depth can encourage larger growth in deeper waters acting as sanctuaries (Collins and McBride 2011). In the Turks and Caicos Islands, off of South Caicos, local Marine Protected Areas have been suggested to also act as sanctuaries, with CPUE inversely correlated with distance from the center of reserves, suggesting spillover of fish into the local fishing zones (Tupper and Rudd 2002). Though, this could also be explained economically, as during the time of the mentioned study tourist preference drove the market price of Nassau Grouper to substantially higher than that of *L. maximus*, which could have influenced fishing in the area (Rudd 2001, Tupper and Rudd 2002, Rudd and Tupper 2002). Protected areas have also been shown to have a positive effect on mating, as in Mexico significantly more successful mating per unit effort has been observed inside of protected areas than outside (Muñoz et al. 2010). Unpublished, underwater visual assessments have previously found the marine reserve of Admiral Cockburn Land and Sea National Park (ACLSNP) to have higher densities of hogfish than neighboring fished locations (Tupper and Rudd 2002). Those data illustrate that protected areas may serve as refuges large enough for this relatively sedentary species, but also indicate that *L. maximus* are vulnerable to high fishing pressure outside the protected areas nearest South Caicos.

Long distance migration of *L. maximus* is not thought to be likely, as recorded ranges of smaller individuals (~ 250 mm TL) are thought to have ranges of around 600 m^2 (Tupper and Rudd 2002) and adults tend to stay in the same generalized area (Knight et al. 2006), even adult males, who are seen to move significantly more than females of equivalent age classes (Muñoz et al. 2010). On a smaller scale, distributions along individual reef shelves are broad but not randomly (Collins and McBride 2011). The highest densities are observed near shore, though fish of common ages are significantly larger farther offshore, suggesting that *L. maximus* grow at a faster rate offshore (Collins and McBride 2011). It is assumed that females complete maturation near shore, because immature females are not observed at depths > 22m (Collins and McBride 2011). Females have also been found to be significantly younger and smaller on average closer to shore, which indicates possible shorter life spans and increased chance of mortality near shore (Collins and McBride 2011). This also suggests that ontogenetic migration offshore occurs with this species, but has not been proven. (Collins and McBride 2011).

L. maximus are broadcast spawners (Robinson and Prince 2003) that mate in harems, having one territorial male to several females (Muñoz et al. 2010). However, unlike species such as the Nassau Grouper that have mass broadcasting aggregations (Choat et al. 2010), *L. maximus* tend to have more frequent aggregations, with females seen spawning daily during the spawning season (McBride and Johnson 2007). Within their protogynous populations male to female ratios (M/F) range from 0.1 - 0.4 (Collins and McBride 2011). Spawning territories for males average 1,300 m^2, and active spawning lasts about an hour, usually between the hours of 1500 and 1800 (Muñoz et al. 2010).

During this spawning time, males have been seen conducting movements along distinct routes on the sea floor, engaging in mating behaviors with females in the area, or interacting in territorial disputes with other males, though aggression and inactions are rarely seen outside of spawning times (Muñoz et al. 2010). Unfortunately, female attachments to a particular harem have yet to be investigated (Muñoz et al. 2010), through males have been seen to engage in greater amounts of general movement than females (Muñoz et al. 2010).

Change in sex from female to male occurs at the end of the spawning season and takes course over several months. The timing of this change is thought to be adaptive to the need for males after the spawning season based on removed individuals, as the change occurs in a multitude of ages and sizes, though largely in individuals with a fork length greater than 300 mm (McBride and Johnson 2007, Collins and McBride 2011). Median size and age of individuals at age of sex change are seen to be significantly less common near shore, thought to be due to fishing pressures (Collins and McBride 2011). If fishing pressure is the cause for reduced *L. maximus* males, the extensive time for the sex change to occur may prove more difficult to recover populations of a single harem or stock (McBride and Johnson 2007).

This study analyzed length based indicators for hogfish landed between 2004 and 2017 in the Turks and Caicos Islands. Specifically, asking:

i) Is the hogfish fishery of the Turks and Caicos Island sustainable in terms of $L_{\text{sexual transition}}$, and
ii) How does hogfish total length in the exploited phase vary through time and space?

METHODS

The Turks and Caicos Islands commercial fleet is comprised primarily of small retrofitted V-hull fiberglass boats with 85 - 200 horsepower engines. Using only free-diving methods, fishers harvest *L. maximus* in depths ranging from 3 meters to 30 meters. Fishermen are opportunistic, in that they work multiple fisheries at any one time, depending on the availability of the species at their fishing location (Medley and Ninnes 1999). The *L. maximus* fishery is concentrated surrounding the island of South Caicos.

Random (sporadic) sampling was conducted for this study from both artisanal and commercial landing locations on South Caicos, in the Turks and Caicos Islands, by the School for Field Studies, dating from 2004 through present 2017. Overall catches were landed between 2 pm and 6 pm, where fishers were sought for permission to measure individuals within the catch. If permission was granted, fishermen would be interviewed to collect demographic information including: depth of catch, fishing method, number of fisher's on the vessel and geographic location of catch based on a map grid (Figure 1). Additionally, several metrics on each individual fish were then collected including Standard Length (SL) (0.1 cm), Fork Length (FL) (0.1 cm), and Total Length (TL) (0.1 cm) using a metric measuring board. Finally, individual weights (0.1 kg) were collected with an H-110 electronic digital hanging scale. It should be noted that most fish landed were already cleaned (gutted), so length/weight relationships were not assessed.

JMP Pro 10 software (SAS Institute, Cary, North Carolina, USA) was used for size distribution analysis. Since data collection was limited and total length data

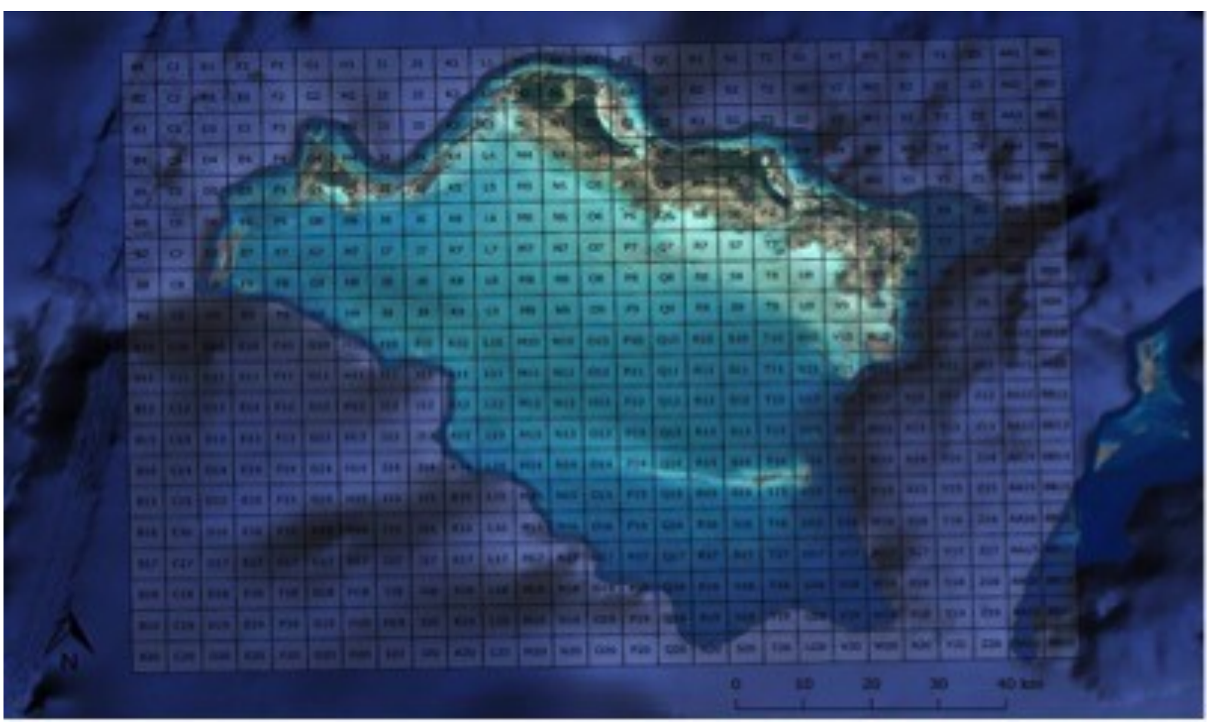

Figure 1. Grid Map of the Caicos Bank, Turks and Caicos Islands for fishermen's visual reference to assess general fishing location by grid square.

showed non-normal distribution, Kruskal-Wallis (n = 1526) tests were utilized for comparison on median sizes (p < 0.05), Further analysis for spatial trends limited the data from 2007 through 2017 (n = 1023), because of lack of geographical information from 2004 through 2006. Geospatial trends in data overtime were analyzed using ArcGIS Pro's Space Time Pattern Mining Toolbox. Based on the grid map system, the XY geographic location was assigned to every data point using the centroid of the corresponding grid square. These points were used to create a Space Time cube using median total length as a summary field, with temporal bins (time step interval) of 6 months. Environmental Systems Research Institute (ESRI's) Emerging Hot Spot Analysis tool was then run to produce medians and analyze trends in the data over time, which was then presented using the Visualize Space Time Cube in 2D tool.

RESULTS

A Shapiro-Wilk test showed that the total length of *L. maximus* was not normally distributed by year (n = 1,526, p < 0.05) or by location (n = 1,023, p < 0.05). The median total length of *L. maximus* from 2004 to 2017 was 35.0 cm (IQR 25.1 cm) but was highly significantly different from year to year using a Kruskal-Wallis Test (Figure 2, n = 1,526, p < 0.0001). In total, 48.5% of the sampled catch had total lengths below the average length of hogfish at sexual transition (35 cm), with 42.7% of the catch below 35 cm in 2010. Peaks in the median were seen every 3 - 4 years from 2004 to 2012, but less variation was observed from 2013 through 2017 (Figure 3). Data collection including geographic locations began in 2007, and using data from all years 2007 to 2017, a Kruskal-Wallis Test showed a significant difference in median total length between grid locations where *L. maximus* was captured (Figure 4, n = 1,023, p < 0.01) and graphically represented in ESRI (Figure 7).

ESRI's Emerging Hot Spot Analysis tool utilizing the Getis-Ord Gi* test showed two of the locations to have upward trends in median total length over time (Figure 8, n = 1023, p < 0.05). Trends in fishing intensity per 6 month bin was also viewed (Figure 5) and a Getis-Ord Gi* test showed three locations to be trending upward, though only two of them significant to a 95% confidence interval (Figure 6, n = 1,023, p < 0.05).

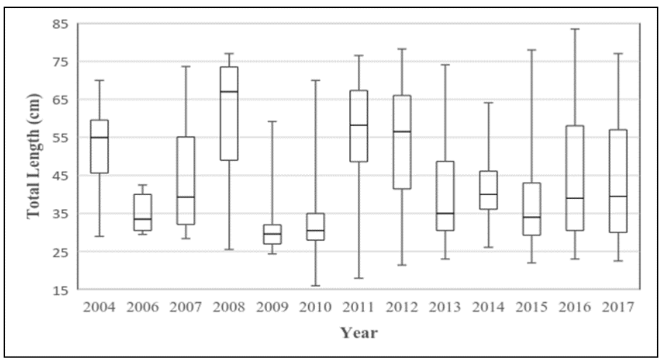

Figure 2. Box plot of median total lengths (cm) of *L. maximus* by year, showing 2nd and 3rd quartiles, minimum, and maximum.

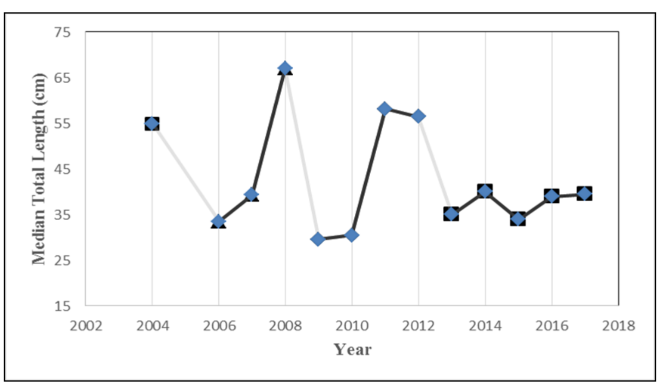

Figure 3. Trends in median total length (cm) of *L. maximus* by year.

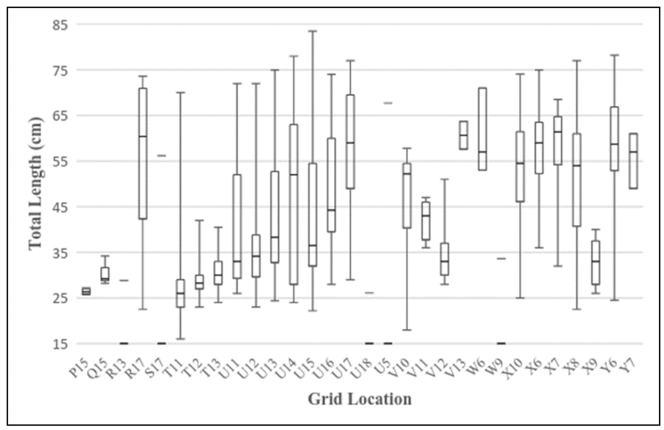

Figure 4. Box plot of median total lengths (cm) of *L. maximus* by grid location, showing 2nd and 3rd quartiles, as well as minimum and maximum.

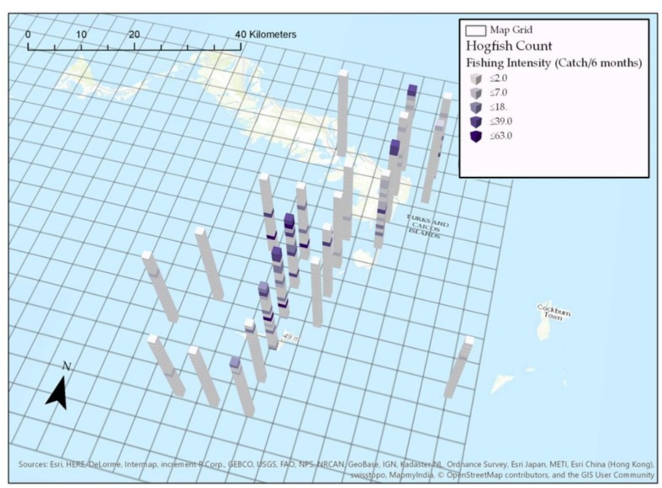

Figure 5. Time Space cubes presenting number of *L. maximus* caught in fishing locations from 2007 (bottom of column) to 2017 (top of column) by 6 month bins.

DISCUSSION

Based on the current collection of sporadic data, finfish landing trends indicate that overall, commercial fishermen are diversifying his/her overall catch of species, which is what has been encouraged by the TCI Government. The *L. maximus* trends in the abundance of catches have fluctuated over the years. However, the abundance of catch and effort data collection is restricted, therefore an evaluation of catch per unit effort (CPUE) could not be assessed in this study. The analysis demonstrates that despite limitations in resources, simple fisher-dependent data collection can detect size structure differences both over time and between hogfish captured less than 6 km apart.

Size variations of individual L. maximus were from 2004 through 2017. A pattern could be observed in median values of total length of *L. maximus,* with peaks occurring every 3 - 4 years suggesting a pattern in the reproductive or growth cycles of the species. This pattern is unique, particularly because *L. maximus* are protogynous, and batch broadcast spawners (McBride and Johnson 2007, Robinson and Prince 2003), indicating that a reduction of males within a harem may affect future breeding sizes. Though spawning and sex change have been seen by other studies to be on the timescale of months or seasons, this pattern suggests a possible large scale spawning cycle, or correlation with other long-term cycles. (McBride and Johnson 2007). The change in this median total length pattern in recent years (2014 - present) could be related to the exploitation (removal) of the larger males of the species in frequented fishing areas. It could also indicate that the fishing pressures may have caused significant stress of the fish population that was inherently affected by environmental conditions and/or habitat degradation (Hurricanes Ike and Hanna 2008). The reduction of larger sexually productive males could then cause a decrease in reproduction rates and halt the typical two-year cycle in recruitment of males, leading to larger reduction in total length in more recent years.

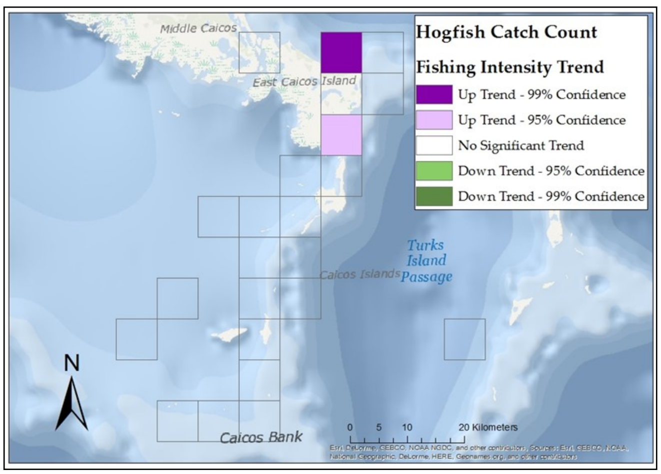

Figure 6. Geographic trends over time of number of caught *L. maximus* using the Getis-Ord Gi* test.

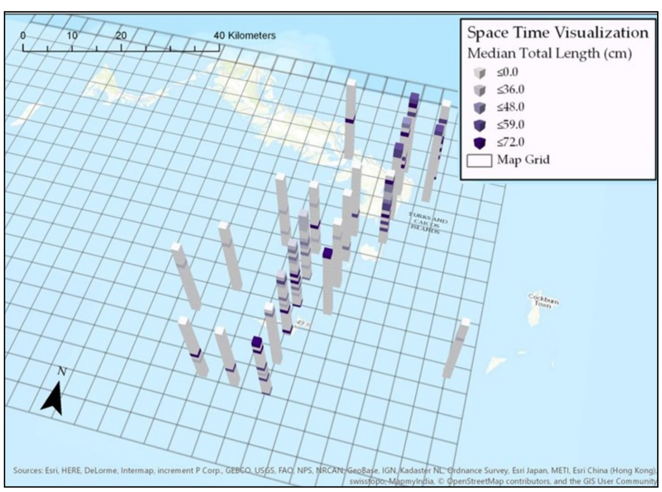

Figure 7. Time Space cubes presenting median Total Length of caught *L. maximus* in fishing locations from 2007 (bottom of column) to 2017 (top of column) by 6 month bins.

A median total length of 35 cm, which is well below $L_{sexual\ transition}$ and below the L_c found for Glover's Reef in Belize (35 cm) (GMFMC 2016). Similarly low values of L_c (25 cm) for *L. maximus* have been related to unsustainable fishing in Puerto Rico (Ault et al 2008). With median total lengths consistently below $L_{sexual\ transition}$ should be classified as non- megaspawners, indicating the status of the hogfish fishery in the TCI seems unsustainable and in need of local management.

Overall, peaks in median total length by year did not match peaks in fishing intensity by year (abundance), though there were significant differences of median total length by grid locations. Upon further analysis, it was determined that there were significant increases in median total length in grid locations with significant increasing trends in fishing reported in different locations. This could suggest one of two concepts:

i) That there is a concentrated population of *L. maximus* with a clumped distribution that the fisherman are utilizing, or

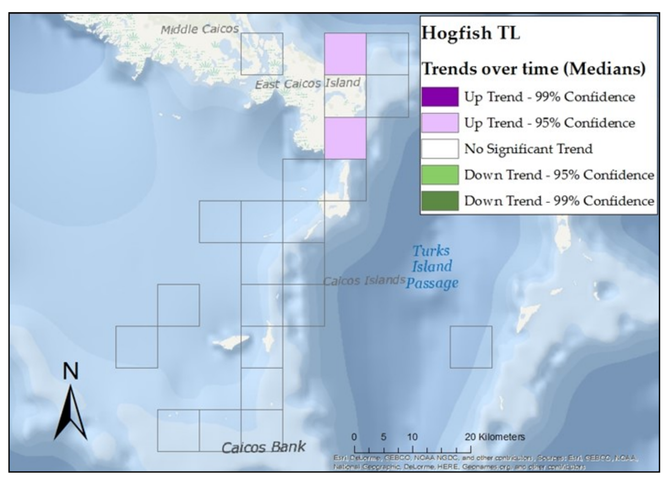

Figure 8. Geographic trends over time of median total length of caught *L. maximus* using the Getis-Ord Gi* test.

ii) That these locations have recently started to be fished more extensively in recent years.

Clusters in population could relate to preferential habitats, as *L. maximus* has been seen to prefer sandy coral rubble and gorgonian microhabitat (Muñoz et al. 2010). However, the increasing total length trends in these areas do not correlate with the stagnating total length trend elsewhere, indicating that fisherman are travelling to different sites to find the larger fish. Additionally, fishing intensities in these areas could be forcing fishermen to dive deeper, which could lead to targeting larger individuals. Unfortunately, there is in-adequate data to confirm this, as depth measurements are fishermen estimates and are estimations. Most catches were reported to be collected by spearfishing, the most common finfish fishing method in the area. The depth range of *L. maximus* is 3 - 40 meters (Choat et al. 2010) and falls within the range of spear fisherman of the area, with the maximum reported free-dive depth being over 22 meters (72 ft). In Florida, offshore (> 30m depth) hogfish are thought to contribute significantly to recruitment in the nearshore (< 30 m) fishery (Angela and McBride 2011). In this manner, offshore reefs themselves act as de facto protected areas, where hogfish can spawn. However, in Florida, the shortest recorded individual found at > 30 m was 2 years old and 32 cm (Angela and McBride 2011). Thus, in order for TCI reefs at > 30 m to help replenish the fishery, hogfish must be protected from being fished out of shallower areas until they are large enough to move to these deeper reefs. However, if populations were to decline in number and size, fishermen would be stimulated to dive at increased depths, which could cause an imbalance fishing pressure on males of the species, as females are rarely seen at depths 22 meters (Collins and McBride 2011).

L. maximus is an important fishery throughout the Caribbean (Bunkley-Williams and Williams 2000), with populations decreasing worldwide (Choat et al. 2010). Understanding reproductive cycles and how they are affected by outside ecological cycles could influence management decisions for this species. In this study a large portion of *L. maximus* captured and measured were under 30 cm total length, let alone 30 cm fork length, the point at which many males are large enough to metamorphose (McBride and Johnson 2007). This could then indicate that most of individuals are fished in shallower close to shore locations that have yet to reach sexual maturity. In both 2009 and 2013, more than half of the measured *L. maximus* individuals were under 30 cm total length. The smaller total lengths could be an indicator for growth overfishing, and hence harem sizes and change patterns in growth and reproduction.

Within the TCI, management strategies often take the course of fisheries restrictions such as size limits, closed seasons and catch limits, because of limited enforcement personnel and financial constraints. However, management strategies that rely solely on minimum size restrictions may not be as effective for hogfish as they are for snapper, given the life-history characteristics of hogfish. Since males are typically larger than females, fishing pressure often leads to size-selection where the male is separated from its female harem. When the male is removed reproduction may cease for the harem of females until a new male is introduced or a female within the harem undergoes sexual transition, which can take an entire year (Kantoussan et al. 2009). If the TCI intends to effectively monitor the hogfish fishery, it must consider management strategies that can encourage the fisheries growth and sustainability.

CONCLUSIONS

The management of any fishery requires monitoring of the stock population and an understanding of the spatial and temporal scales at which the population varies. The study attempted to elucidate this information for the Turks and Caicos *L. maximus* fishery, with broader methodological implications for other growing small-scale fisheries. The analysis recognizes that the path towards sustainability for developing small-scale fisheries is often incremental. Waiting for stock assessments to monitor fisheries too often leads to substantial economic losses prior to management action. In the meantime, basic fisher-dependent data and simple length measurements can indicate the general status of a fishery. Unfortunately, there were limits to this study and therefore any recommendations for implementing size or seasonal restriction to the local government cannot be made at this time, but should open a dialogue for conversation between the local stakeholders. The collection of additional data can build local research capacity, provide access to catch and effort limitations (depth), and hopefully, catalyze the creation of monitoring and management regimes. The analysis suggests these regimes should be developed with consideration of the spatial scales (GPS location), with which fish population structures may vary.

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LITERATURE CITED

Collins, A.B. and R.S. McBride. 2011. Demographics by depth: spatially explicit life-history dynamics of a protogynous reef fish. *Fisheries Bulletin* **109**(2):232-242.

Ault, J.S., S.G. Smith, and J.A. Bohnsack. 2005. Evaluation of average length as an estimator of exploitation status for the Florida coral-reef fish community. *ICES Journal of Marine Science: Journal du Conseil* **62**(3):417-423.

Ault, J.S., S.G. Smith, J. Luo, M.E. Monaco, and R.S. Appeldoorn. 2008. Length-based assessment of sustainability benchmarks for coral reef fishes in Puerto Rico. *Environmental Conservation* **35**:221.

Babcock, E.A., R. Coleman, M. Karnauskas, and J. Gibson. 2013. Length -based indicators of fishery and ecosystem status: Glover's Reef Marine Reserve, Belize. *Fisheries Research* **147**:434-445.

Bianchi, G. 2000. Impact of fishing on size composition and diversity of demersal fish communities. *ICES Journal Marine Science* **57**:558-571.

Bunkley-Williams, L. and E.H. Williams, Jr. 2000. *Nerocila benrosein*. sp. (Isopoda: Cymothoidae), an external parasite of hogfishes from the northern Bahamas. *The Journal of Parasitology* **85**(6):1036-1040.

Canales, C.M., J.B. Company, and P.M. Arana. 2016. Spatio-temporal modelling of the maturity, sex ratio, and physical condition of nylon shrimp *Heterocarpus reedi* (Decapoda, Caridea), off Central Chile. *Fisheries Research* **179**:1-9.

Choat, J.H., D. Pollard, and Y.J. Sadovy. 2010. *Lachnolaimus maximus*. The IUCN Red List of Threatened Species 2010:e.T11130A3252395. http://dx.doi.org/10.2305/IUCN.UK.2010-4.RLTS.T11130A3252395.en. 30 March 2017.

Collins, A.B. and R.S. McBride. 2011. Demographics by depth: spatially explicit life-history dynamics of a protogynous reef fish. *Fishery Bulletin* **109**(2):232-242.

Ehrhardt, N.M. and J.S. Ault. 1992. Analysis of two length based mortality models applied to bounded catch length frequencies. *Transactions of the American Fisheries Society* **121**:115-122.

Froese, R. 2001. Keep it simple: three indicators to deal with overfishing. *Fish and Fisheries* **5**:86-91.

GMFM — NOAA (Gulf of Mexico Fishery Management Council Pursuant to National Oceanic and & Atmospheric Administration Award). 2016. *Final Amendment 43 to the Fishery Management Plan for the Reef Fish Resources of the Gulf of Mexico: Hogfish Stock Definition, Status Determination Criteria, Annual Catch Limit, and Size Limit, including Environmental Assessment, Fishery Impact Statement, Regulatory Impact Review, and Regulatory Flexibility Act Analysis*.

Haedrich, R.L. and S.M. Barnes. 1997. Changes over time of the size structure in an exploited shelf fish community. *Fisheries Research* **31**:229-239.

Humann, P. and N. DeLoach. 2011. *Reef Fish Identification: Florida Caribbean Bahamas. Fifth Edition*. New World Publications, Inc. Jacksonville, Florida USA. 481 pp.

Kantoussan, J. et al. 2009. The relevance of size parameters as indicators of fishery exploitation in two West African reservoirs. *Aquatic Ecology* **43**:1167-1178.

Kendall, N.W. and T.P. Quinn, T. P. 2013. Size-selective fishing affects sex ratios and the opportunity for sexual selection in Alaskan sockeye salmon *Oncorhynchus nerka*. *Oikos* **122**:411-420.

Knight, A., L. Kaufman, and S. Miller. 2006. A pilot study of hogfish (*Lachnolaimus maximus* Walbaum 1792) movement in the Conch Reef Research Only Area (northern Florida Keys). NOAA/National Ocean Service/National Marine Sanctuaries Program. Silver Spring Spring, Maryland USA.

Lambert, G., J.R. Nielsen, L.I. Larsen, and H. Sparholt. 2009. Maturity and growth population dynamics of Norway pout (*Trisopterus esmarkii*) in the North Sea, Skagerrak, and Kattegat. *ICES Journal Marine Science* **66**:1899-1914.

Mahon, R. 1997. Does fisheries science serve the needs of managers of small stocks in developing countries. *Canadian Journal of Fisheries and Aquatic Science* **54**:2207-2213.

McBride, R.S., M. Johnson, L. Bullock, and F. Stengard. 2001. Preliminary observations on the sexual development of Hogfish, *Lachnolaimus maximus* (Pisces: Labridae). Florida Fish and Wildlife Conservation Commission. St. Petersburg, Florida USA.

McBride, R.S. and M.R. Johnson. 2007) Sexual development and reproductive seasonality of hogfish (Labridae: *Lachnolaimus maximus*), a hermaphroditic reef fish. *Journal of Fish Biology* **71**(5):1270-1292.

McBride, R.S. and A.K. Richardson. 2007. Evidence of size-selective fishing mortality from an age and growth study of hogfish (Labridae: *Lachnolaimus maximus*), a hermaphroditic reef fish. *Bulletin Marine Science* **80**:401-417.

Medley, P. and C.H. Ninnes. (1999). A stock assessment for the conch (*Strombus gigas* L.) fishery in the Turks and Caicos Islands. *Bulletin Marine Science* **64**:399-406).

Muñoz, R.C., M.L. Burton, KJ. Brennan, and R.O. Parker. 2010. Reproduction, habitat utilization, and movements of hogfish (*Lachnolaimus maximus*) in the Florida Keys, USA: comparisons from fished versus unfished habitats. *Bulletin of Marine Science* **86** (1):93-116.

Pauly, D. and D. Zeller. 2016. Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. *Nature Community* **7**:10244. DOI10.1038/ncomms10244

Quinn, T.J. and R.B. Deriso. 1999. *Quantitative Fish Dynamics*. Oxford University Press, Oxford, England. 542 pp.

Quinn, T.J. 2003. Ruminations on the development and future of populations dynamics models in models in fisheries. *Natural Resource Model* **16**:341-392.

Randall, J.E. 1967. *Food habits of Reef Fishes of the West Indies*. Institute of Marine Sciences, University of Miami. Miami Florida USA. http://www.aoml.noaa.gov/general/lib/CREWS/Cleo/PuertoRico/prpdfs/randall-habits.pdf

Robinson, M.P. and J.S. Prince. 2003. Morphology of the sperm of two wrasses, *Thalassoma bifasciatum* and *Lachnolaimus maximus* (Labridae, Perciformes). *Bulletin of Marine Science* **72**(1):247-252.

Rudd, M.A. 2001. The effects of seafood import tariffs on market demand for Nassau grouper in the Turks and Caicos Islands. *Proceedings of the Gulf Caribbean Fisheries Institute* **54**:1-12.

Rudd, M.A. and M.H. Tupper. 2002. The impact of Nassau grouper size and abundance on scuba diver site selection and MPA economics. *Coastal Management* **30**(2):133-151.

Sadovy, Y. 2001. The threat of fishing to highly fecund fishes. *Journal Fisheries Biology* **59**:90–108.

Shepherd, S.A., J.B. Brook, and Y. Xiao. 2010. Environmental and fishing effects on the abundance, size and sex ratio of the blue-throated wrasse, Notolabrus tetricus, on South Australian coastal reefs. *Fisheries Management. Ecology* **17**:209–220.

TCI, Turks and Caicos Islands Government. 2005. National Plan for Managing the marine fisheries of the Turks and Caicos Islands 2005-2010.

Tupper, M. and M.A. Rudd. 2002. Species-specific impacts of a small marine reserve on reef fish production and fishing productivity in the Turks and Caicos Islands. *Environmental Conservation* **29**(04):484-492.

Ulman, A., L. Burke, E. Hind, R. Ramdeen, and D. Zeller. 2016. Conched Out: Total Reconstructed Fisheries Catches for the Turks and Caicos Islands Uncover Unsustainable Resource Usage. *Frontiers in Marine Science* **3**:71.

Worm, B. et al. 2009. Rebuilding Global Fisheries. *Science* 325:578-585.