Assessing Shell-based Legal-Size Compliance When Queen Conch are Not Landed in the Shell: A Puerto Rico Case Study

Evaluando el Cumplimiento del Tamaño Legal Basado en la Concha Cuando el Caracol Rosado no es Desembarcado Intacto: Un Estudio de Caso de Puerto Rico

L'évaluation de la Conformité à la Taille Légale Basée sur la Coque Lorsque Lambi ne sont pas Débarqués Intact: Une étude de Puerto Rico de Cas

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ABSTRACT

Intensive exploitation on queen conch led to the species' listing under CITES, forcing national and regional agencies to develop and implement management plans to certify sustainability, which frequently use shell-based minimum size limits. Yet, enforcement of these regulations requires landing the conch intact, and fishers argue that this reduces efficiency, while negatively affecting both diving and boating safety. This study examined the morphology of queen conch to establish if there are alternative measures useful for enforcing existing regulations without requiring the shells to be landed. In Puerto Rico, current management regulations include a 9-inch (22.86 cm) minimum shell length or 3/8-inch (9.5 mm) minimum lip thickness. From nine locations around Puerto Rico, conch were assessed for sex, maturity and 9 morphometric measurements. Regression analyses focused on differences between juveniles (no shell-lip), thin-lipped (< 10mm) adults and thick-lipped (10 mm) fully mature adults, and conch smaller or $\geq$ 229 mm. Despite strong linear relationships, there were no clear patterns separating legally from illegally harvest conch, due to the large variability within and among conch from different areas. While no single factor could account for both shell length and lip-thickness, a combination of approaches could be used to approximate the legal status of harvested conch. These were a minimum operculum length of 2.75 inches (70 mm) or the presence of fully developed reproductive structures (verge/egg groove), with a maximum of 10% of the catch departing from these size-based criteria. Implementation would require training enforcement personnel to measure the operculum and to recognize the male/female sexual structures.

KEYWORDS: Queen conch, legal size, morphology

INTRODUCTION

Queen conch, *Lobatus* (= *Strombus*) *gigas*, is a valuable resource both commercially and recreationally in the Caribbean. In Puerto Rico, scuba divers that target queen conch are among the most successful commercial fishermen on the island (Matos-Caraballo et al. 2012). After spiny lobster, queen conch contributes most to overall commercial landings (~11%). In 2007, a total of 65,300 kg (143,653 lb) meat weight was caught by commercial fishers. At an average price of $3.78 USD per pound (Matos-Caraballo et al. 2012), the commercial fishery is valued at around $543,000 USD.

Management of this commercially important species throughout the Caribbean is difficult due to a variety of factors. Key among these is that conch change the manner in which they grow. As juveniles, they increase in shell length, but at about the onset of maturity they cease growing in length and form a broad shell lip that thickens over time (Appeldoorn 1988; Tewfik et al. 1998). As a consequence, length of conch are fixed at the time of maturation and, while some biomass increase does occur after maturation, final biomass is predominately a function of size, not age (Appeldoorn 1988). Additionally, there is a wide variation in the size at maturity, with a strong environmental influence. Thus, length and biomass are not a function of age (Appeldoorn 1988). At present, there is no established way to age conch that could be used in standard growth models for assessment. In addition, conch require copulation for reproduction, and maintaining minimum densities is important, yet exact densities needed are difficult to assess (Stoner and Ray-Culp 2000, Appeldoorn et al. 2011a). In addition, genetic connectivity of individual stocks is generally not known. Yet conch are vulnerable to overfishing; they are slow moving with limited home ranges (*e.g.,* Delgado and Glazer 2007), and during the extended reproductive season (Avila-Poveda and Baqueiro-Cárdenas 2009) they migrate to shallower depths and preferentially inhabit sandy bottoms where they are conspicuous and easy to catch (Randall 1964, Weil and Laughlin 1984, Coulston et al. 1987). In 1992, following the collapse of conch fisheries in a number of countries, conch were listed under Appendix II of CITES. This requires exporting countries to certify through their local scientific authority that harvest and export are not negatively affecting the stock. This has helped by forcing exporting countries to collect non-detrimental findings to ensure export does not negatively affect the wild population (Theile 2001).

The queen conch resource in Puerto Rico is managed jointly by the territorial and U.S. federal governments. From the shoreline out to 9 nautical miles (NM) (16.87 km), the regulations governing harvest are mandated by the territorial government. Outside 9 NM is the United States' Exclusive Economic Zone (EEZ), where the federal government oversees and imposes regulations regarding queen conch harvest through the Caribbean Fisheries Management Council. In 1997, the US Caribbean EEZ, with the exception of St. Croix (US Virgin Islands) was closed to conch fishing. Also at this time, a closed season was implemented in territorial waters (1 July to 31 September), later amended to 1 August to 31 October in 2012. In 2004, additional regulations in local waters included a 9-inch (22.86 cm) minimum shell length or 3/8-inch (9.5

mm) minimum lip thickness and a bag limit of 150 and 450/day per person and per boat, respectively.

The use of shell-based size limits requires that conch be landed in the shell for enforcement purposes. However, fishermen have identified that this significantly:

i) Decreases their fishing efficiency by having to spend excessive time raising whole conch to the surface,
ii) Increases the risk of diving accidents by having to offset this extra time with longer dive times or number of dives, and
iii) Decreases boater safety due to the extra weight and volume of up to 450 conch shells.

The purpose of this study was to examine the morphology of queen conch to establish if there are alternative measures that can be used to enforce the existing regulations without requiring the shells to be brought to shore.

METHODS

Morphometric data were collected from nine locations on the west, south and east coasts of Puerto Rico. Sampling was done under permit by commercial conch fishermen, who were requested to collect all conch encountered (juveniles and adults). This was done to ensure that there would be a significant range of sizes to develop statistically rigorous regressions comparing various morphological measures. Table 1 gives the sampling sites, their approximate locations, depth, and habitat type as reported by the fishermen.

For each individual, sex, maturity state and morphometric data (Table 2) were collected. Linear dimensions were to the nearest 1 mm, weights were to the nearest 1 g, and volumes were to the nearest 10 ml. Volumes were measure only on every tenth individual. Some fisherman classified conch into different morphotypes based on size, number/length of spines, color, etc., and these were recorded as appropriate. Four morphotypes were identified: *flin*, common, *tonino* and *tonino con punto*. Figure 1 shows a representative of each morphotypes. Photographs were taken of selected specimens on the first sampling date and then of every specimen after that. Additionally, tissue samples from the mantle for potential future genetic analysis were collected on a subsample of individuals, usually the first 60.

Following Mueller and Stoner (2013), operculum ratio was calculated as the operculum length/operculum width. Opercula from conch sampled on May 13 and June 12 were measured on fresh specimens. Opercula from all other samples were frozen prior to being measured. No operculum widths were taken on March 4. Opercula from May 13 were subsequently frozen and a t-test was performed to assess if the results from the measurements on frozen and fresh samples were different.

Regression analyses were conducted with two goals. The first was to determine if there were any significant shifts in morphometric relationships that occur at the time of maturation (*i.e.,* that could be related to the lip-thickness regulation) or at a shell length of 9 inches. The second was to quantify the degree of variability (variance) in these

Table 1. Location, depth and habitat of sampling sites, with number of queen conch sampled.

Date	Latitude	Longitude	Depth(ft)	Habitat	Adults	Juveniles	Total
23-Jan-14	17.94300	-67.00781	50	Sand plain	16	34	50
21-Feb-14	17.88835	-67.18532	70	Hard bottom with gorgonians and sponges	35	65	100
4-Mar-14	17.93091	-67.31075	65	Coarse sand/rubble with brown algae	70	6	76
6-Mar-14	17.93898	-67.30705	60	Sand with brown algae near reef	41	24	65
26-Mar-14	17.90896	-67.28980	78	Sand with Algae (Rastreal)	26	17	53
24-Apr-14	17.88658	-67.19851	75	Hard bottom	19	53	72
13-May-14	17.93351	-67.26101	-		64	27	91
12-Jun-14	18.36350	-65.60417	-		86	10	96
27-Jun-14	18.32083	-65.43750	80-85	Algal Plain (Pasto)	78	1	79

Table 2. Morphological measures and other parameters recorded for each individual.

Parameter	Definition
Shell length	Maximum shell length from the tip of the spire to the siphon
Lip thickness	Minimum lip thickness measured 4 cm in from the lip along the mid third of the length
Operculum length	Maximum length of the operculum
Operculum width	Maximum width of the operculum perpendicular to the operculum length
Tissue weight	Weight of all tissue extracted from the shell (may not be total tissue)
Uncleaned meat weight	Tissue weight minus the visceral mass and some of the mantle
Cleaned meat weight	Uncleaned weight minus the mantle, operculum, verge, eyes and proboscis
Uncleaned meat volume	Volume of the uncleaned meat measured by liquid displacement
Clean meat volume	Volume of the cleaned meat measured by liquid displacement
Maturity	Mature or juvenile determined by the presence/absence of a fully formed verge or egg groove following Appeldoorn (1988)
Sex	Male or female determined by presence of a full or developing verge or egg groove following Appeldoorn (1988)
Morphotype	As classified by fishermen

relationships. This was done on the assumption that a single morphological measure (*e.g.*, weight or volume) could be used to represent conch legally harvested under existing size limits, but that the measure would have to account for the expected degree of variance in that measure, for example by using an average measure or allowing for a fixed percentage of the harvest to be below the size limits at the time of enforcement.

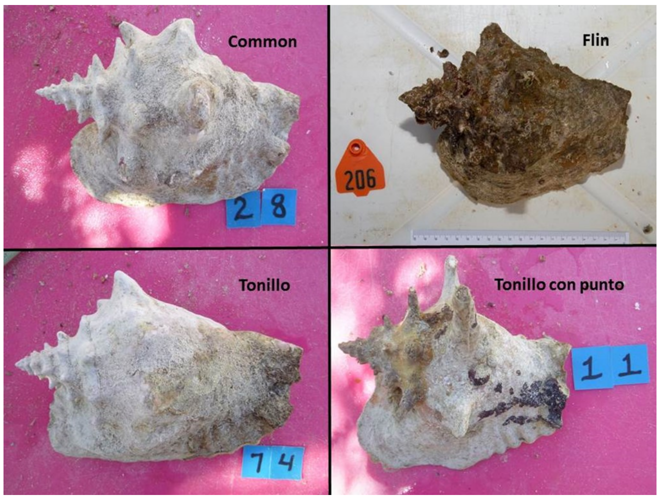

Figure 1. Representative images of the four morphotypes of queen conch identified by fishermen.

Regressions were calculated on the following pairs of measurements:

i) Shell length versus Operculum length,
ii) Operculum width,
iii) Operculum ratio,
iv) Uncleaned meat weight and Cleaned meat weight,
v) Operculum ratio versus Lip thickness,
vi) Weight (uncleaned meat) versus Volume, and
vii) Weight (cleaned meat) versus Volume.

The shell length versus operculum length regression was pooled between sites, but separated between juveniles, adults < 10 mm lip thickness and adults > 10 mm lip thickness. The same is true for the shell length versus operculum width analysis. For the shell length versus operculum ratio regression, analyses were pooled between sites, but separated for fresh and frozen measurements and separated for juveniles, adults with a lip <10mm and adults with a lip ≥ 10 mm. The analysis was also done for each site on its own, and separated between juveniles and adults. For the lip thickness versus operculum ratio, analysis was again pooled for all sites, separated for fresh and frozen measurements, and separated for adults < 229 mm shell length and adults ≥ 229 mm shell length. This analysis was also done for each site separately, with just adults. Shell length versus weight regressions were pooled for all sites, but separated into juveniles, adults < 10 mm lip thickness and adults ≥10mm lip thickness. Volume to weight regression was pooled for all sites and age classes.

A regression was also done between the operculum ratio and the proportion of mature conch. Ratio bins of 0.22 width, starting at 2.41 and ending at 4.01 were created, and the percentage of mature conch were calculated using both lip thickness ≥ 10 mm and presence of reproductive structures to define maturity. These divisions were chosen to ensure there was enough conch in each bin, and conch with ratios that were far outside the bin limits were excluded (n = 2). Juveniles were assigned a lip thickness of zero.

RESULTS

All regressions showed strong linear relationships between the various morphometric measures. However, there were no clear patterns that would cleanly separate legally harvested from illegally harvest conch, due to the large degree of variability observed within and among conch from different areas. For example, Figure 2 shows an example of the relationship between shell length and weight. No single regression line accurately describes the length-weight relationship across juveniles and adults. For a given shell length, the thick-lipped adults have on average a higher weight than either juveniles or thin-lipped adults, and this increases the overall variation in the length -weight relationship. This higher weight reflects the degree of weight added during and subsequent to maturation but when the shell length remains constant or even erodes slightly. Adding to the variability is the fact that different fishermen clean conch to different degrees.

The red horizontal line in Figure 2 is arbitrarily drawn to be just above the largest juvenile weight and corresponds to a cleaned meat weight of 160 g. Such a cutoff would clearly separate juveniles from adults, but not from still maturing adults. It would also invalidate a large fraction of legally caught mature but small (light weight) adults.

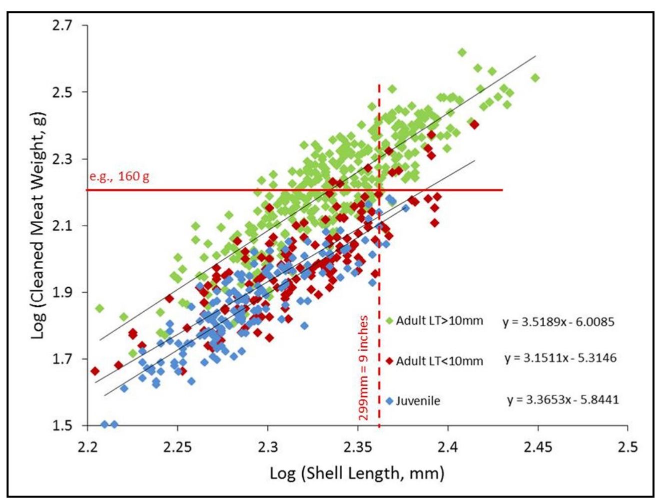

Figure 2. Relationship between Log_{10}(shell length) and Log_{10}(cleaned meat weight) for juvenile, thin-lipped (<10 mm) adult and thick-lipped (≥10 mm) adult queen conch. LT = shell lip thickness. Dashed vertical line marks the legal shell length of 229 mm (9 inches). Horizontal line marks a cleaned meat weight of 160 g.

Figure 3 shows a similar graph but sorted by morphotype. From this it can be seen that there is no difference between the length-weight relationships for either juveniles or adults based on morphotype (note that the *flin* adults sampled have significantly thinner lips [mean 10 mm] compared, for example to common adults [mean 20 mm]). However, the *flin* morphotype consists of smaller adults, while there are no small adults among the *tonillo* or *tonillo con punto* morphotypes. None of the *flin* conch surpass the 9-inch minimum shell length limit (approximately 2.36 on a $\log_{10}$ scale).

Use of a volume measure as a proxy for weight would show a similar pattern due to the tight relationship between meat weight and volume (Figure 4). However, this relationship is not without its own sources of variation. As seen in the figure, conch sampled on May 13 have a significantly different weight-volume relationship for conch sampled from all other sites. This variation cannot be attributed to measurement error.

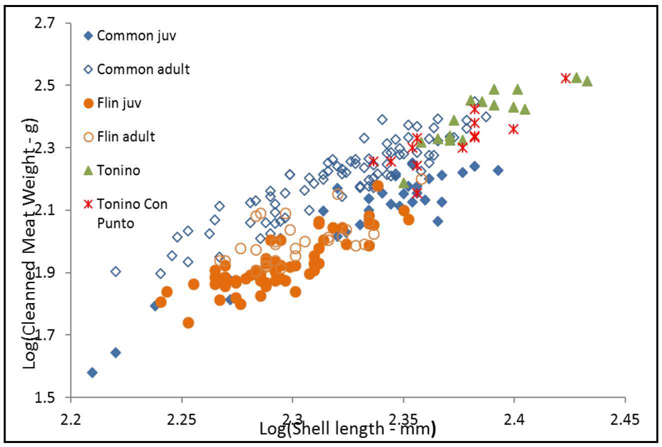

Figure 3. Relationship between Log_{10}(shell length) and Log_{10}(cleaned meat weight) for juvenile and adult conch by morphotype.

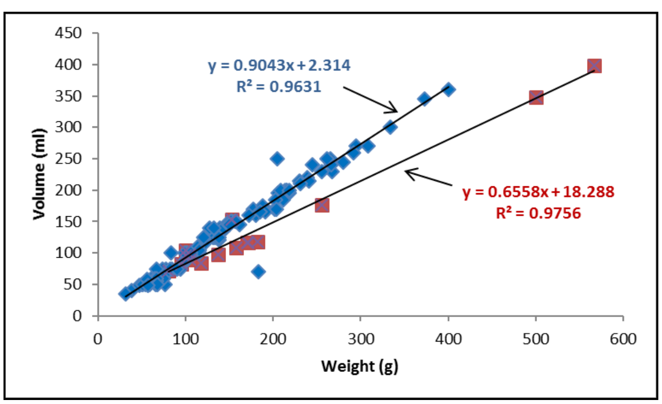

Figure 4. Relationship between cleaned meat weight and volume for queen conch. Brown indicates data from conch sampled on May 13, 2014 (see Table 1); blue indicates data from all other conch sampled.

Following Mueller and Stoner (2013), Figure 5 shows the relationship between the operculum length:width ratio and probability of being mature, as indicated by either a lip thickness ≥ 10 mm or the presence of a fully developed egg groove (females) or verge (males). The sharp change in the probability as the ratio changes between 3 and 3.5 suggests that ratio could be used as an index of maturity. This is particularly so for lip-thickness, which shows the greatest change. The lip-thickness relationship was modeled using the Richards function, a generalized logistic equation that allows for asymmetry:

$$Prob(Lip > 10) = A + \frac{K - A}{((1 + Qe^{-B(Ratio-M)})^{1/v})}$$

where A and K are the lower and upper asymptotes; B is the rate of increase, v affects the symmetry of the curve, M and Q are model parameters and Ratio is the operculum length:width ratio. The estimated model parameter values are as follows:

$K = 0.319$	$A = 0.878$	$B = 0.299$
$M = 3.192$	$v = 0.028$	$Q = 2.136$

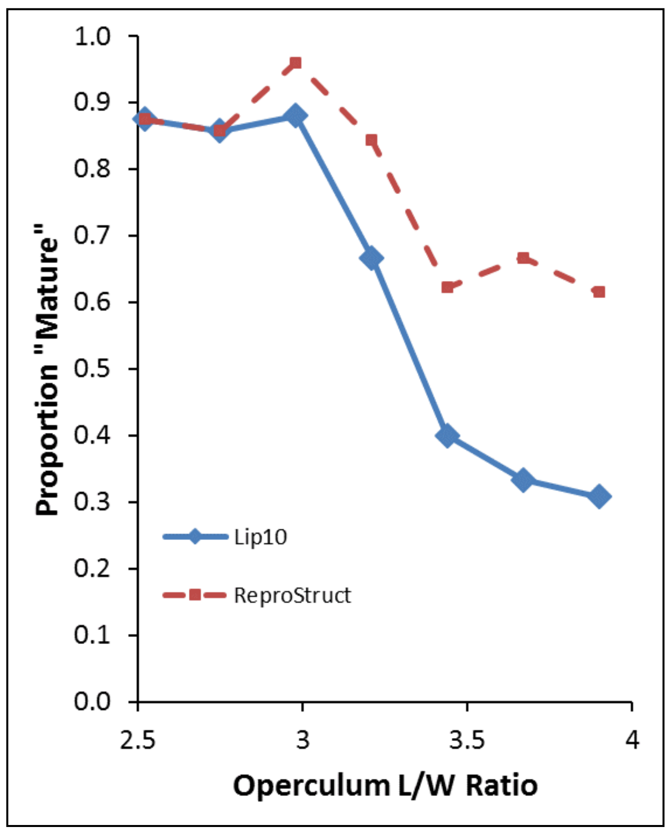

Figure 5. Relationship between the Operculum length:width ratio and the proportion of "mature" conch according to two indicators: 1) a lip-thickness of 10 mm (solid line), 2) presence of fully formed reproductive structures (egg groove or verge) (dashed line). Data are from two sampling sites only.

While the model fits the data well (Figure 6), the usefulness of this approach is limited because the upper and lower asymptotes do not converge on 100% and 0%, respectively. Thus, at high ratio values 32% of the "juvenile" conch would actually be adults, while at low ratio values 12% of the "adults" would still be juveniles. Additionally, since the curve is not vertical in between the two asymptotes, there is substantial uncertainty at mid-ratio values.

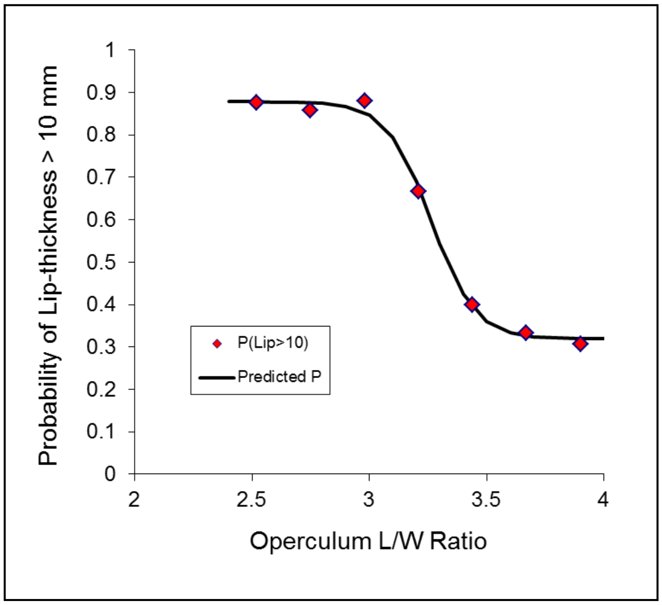

Figure 6. Predictive model (solid line) of the proportion (P) of mature conch (using a lip-thickness greater than 10 mm as an indicator of maturity) based on the operculum length:width ratio.

Figure 7 shows the relationship between shell length and operculum length. While few juveniles are found above the legal limit of 9 inches (229 mm), there are many adults below 9 inches that could be legally harvested. Using the predicted mean operculum length (2.75 inches) as a proxy for shell length of 9 inches has similar results, but would result in some conch being legally caught but enforced as being illegal (lower right), while other conch would be considered legal, when in fact they were harvested undersized (upper left). The operculum length could be adjusted to eliminate falsely categorizing legally harvested conch, for example to 3 3/8 inches (60 mm), but due to the high variance in the data this would allow a high proportion of otherwise illegally harvested juveniles to be considered legal.

Additionally, there is some site variability in the relationship between shell length and operculum length (Figure 8). While most of the samples follow the general pattern, the site sampled on February 21 shows a different relationship. This site was specifically harvested to sample the *flin* morphotype (90% of the sample), which is characterized by small adults. The corresponding regression analysis shows that, on average, a conch sampled on that date had an operculum length that was approximately 5 mm shorter than expected based on conch sampled across all sites. Based on this figure almost all of the conch would be assessed as being undersized by both fishers and enforcement personnel, except for those that were fully mature (adults with lip-thickness $\geq$ 10 mm) (Figure 9).

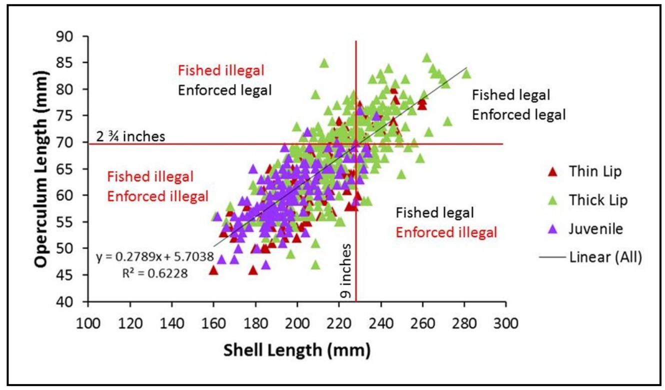

Figure 7. Relationship between queen conch shell length and operculum length for juveniles, thin-lipped (<10 mm) adults and thick-lipped ($\geq$10 mm) adults, plus the linear regression pooled for all individuals. Red vertical line is at 9 inches (229mm) shell length and separates conch harvested above (right) and below (left) the minimum shell length. Red horizontal line is at 2.75 inches (70 mm) operculum length, which is recommended as a proxy for assessing compliance with the 9-inch size limit.

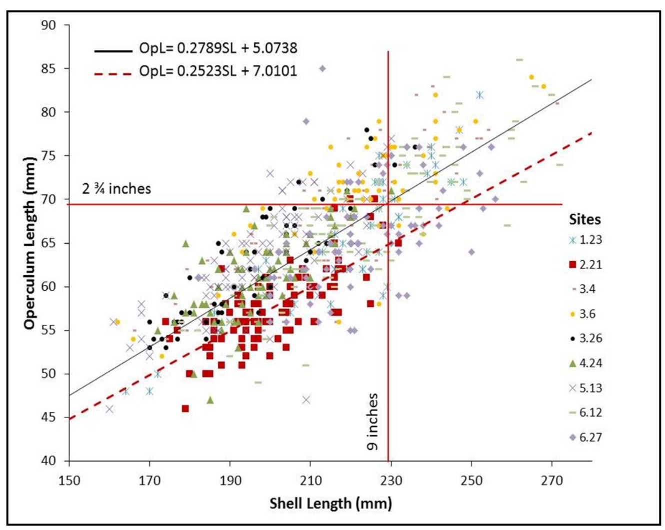

Figure 8. Relationship between queen conch shell length and operculum length by sample location (=date), plus the linear regression pooled for all individuals and for site 2.21. Red vertical line is at 9 inches (229mm) shell length and separates conch harvested above (right) and below (left) the minimum shell length. Red horizontal line is at 2.75 inches (70 mm) operculum length, which is recommended as a proxy for assessing compliance with the 9-inch size limit.

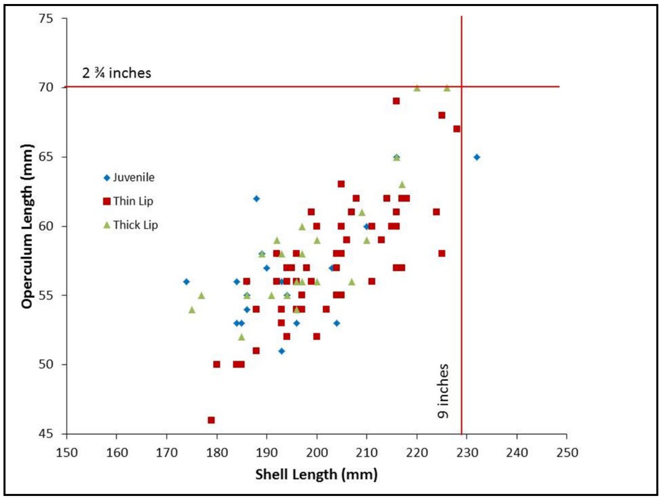

Figure 9. Relationship between queen conch shell length and operculum length for juveniles, thin-lipped (<10 mm) adults and thick-lipped (≥10 mm) adults for all individuals sampled on February 21(site 2.21). Red vertical line is at 9 inches (229mm) shell length and separates conch harvested above (right) and below (left) the minimum shell length. Red horizontal line is at 2.75 inches (70 mm) operculum length, which is recommended as a proxy for assessing compliance with the 9-inch size limit.

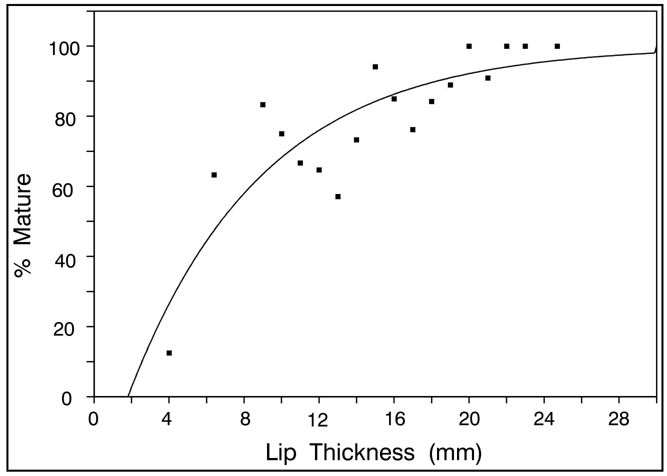

Figure 10. Relationship between shell lip-thickness and percent maturity for queen conch sampled off La Parguera, PR. (From Posada et al. 1997).

DISCUSSION

Size limits in fisheries management are often used to achieve a higher yield-per-recruit, maintain spawning stock or both. For queen conch, size limits based on shell dimensions were designed to increase the probability of conch reaching sexual maturation before harvest. Based on previous studies, the lip-thickness size limit is indeed linked to the onset of maturation (Figure 10). In contrast, the length-limit only ensures that small juveniles will not be harvested, but allows the harvest of the large juveniles of those individuals that would eventually become large adults. Together, these two regulations have a mixed effect. The length limit puts a minimum size on juveniles, which helps to maintain a larger yield-per-recruit. However, those individuals destined to become large adults can be harvested while still juvenile. Since fecundity is largely a function of size (other factors being equal), this disproportionally reduces potential reproductive output. Additionally, to the degree that size is determined genetically, and depending upon the rate of fishing mortality, this leads over time to the potential selection of smaller conch. However, it is thought that environmental factors are primarily responsible for the determination of final shell length (Appeldoorn 1994). In combination with the length limit, the lip-thickness size limit ensures that the majority of small adults will reach sexual maturation before being eligible for harvest. It does not protect adults that would be larger than 9 inches, since they could be legally harvested before reaching sexual maturity.

The use of morphological-based regulations for queen conch is subject to a number of limitations not typical for other species. As mentioned earlier, these include (1) the change in shell growth pattern at maturity, and (2) the high site (environmental, morphotype) variability in the size and morphology of conch. To this must be added a third limitation, and that is the differential ability of fishermen (using shell characteristics) and enforcement personnel (using non-shell characteristics) to be able to determine the legal status of an individual conch. There is no simple or direct conversion from shell-based to non-shell-based criterion. Even worse, there is no single conversion that would address the two different criteria for minimum size: shell length and shell lip-thickness.

These problems can be illustrated by re-examining Figure 2, which shows the shell length-meat weight relationship. First, with respect to length, legality at the time of harvest is determined by a vertical cutoff, in this case the vertical dashed line. Any conch to the right of that line would be legal to harvest. However, using any form of length-weight conversion related to that size results in enforcement based on a horizontal line, with anything above the line being considered legally caught. As Figure 2 shows, this will result in legal conch being enforced as illegal (lower right quadrant) and illegal conch being considered legal (upper left quadrant). One can change the proportions of these by moving the horizontal line up or down, but the problem remains. In this case the problem is made worse by the additional weight put on as adults mature, but without a corresponding increase in shell length. As such there is a large variance in weight for any given length. For this reason, any measure based on weight *(e.g.,* individual weight, average weight, number conch/lb or number of conch per volume) is going to be problematic.

Much (although not all!) of the problem of separating legal and illegal conch can be solved by using an additional measure to determine maturity status, which should be highly correlated with lip-thickness. The use of the operculum length:width ratio was found to be unsuitable in this regard. Although there is a significant change at the time of maturation (Figures 5, 6), the change still occurs over a broad range, and even before or after the change there is a significant error rate in predicting maturation status. An alternative is to look at the reproductive structures directly. A fully developed verge in males and egg groove in females can be used to determine if an individual is sexually mature (Appeldoorn 1988) (Figure 11).

An alternative approach, then, is to use operculum length in conjunction with the presence/absence of mature reproductive structures (verge and egg groove). This approach is illustrated in Figure 7. The approach is similar to that of Figure 2 in that, based on shell and operculum lengths alone, the figure can be divided into 4 quadrants according to the assessment of legality by the fisher (shell length) or the enforcement agent (operculum length). However, if conch were also assessed by their maturity status, it can be seen that almost all juveniles fall into the lower left quadrant, where they would be correctly assessed as being illegal by both fishers and enforcement agents. The quadrant of major concern is the lower right, representing those legally harvested but assessed as being illegal by enforcement agents. In this sample, of the 133 conch (out of 682) that were greater than or equal to 229 mm (9 inches) in shell length (= legally harvested), there are only 8 individuals that also had operculum lengths below 70 mm (2.75 inches) AND were not mature, equaling only 6%. In terms of the total catch that a fisher might bring to the dock, the percentage would be much less due to the large fraction of mature but small adults that could be legally harvested (*i.e.*, below 9 inches, but sexually mature).

The site-specific variability in conch, as exemplified by the February 21 sample that consisted primarily of the *flin* morphotype, does not change the situation above. In this case, all of the adults are smaller than the legal shell length, but would be correctly assessed based on reproductive structures. Only one juvenile was found to be above the minimum shell length (Figure 9), which would be legal to harvest but assessed as being illegal (lower right quadrant), yielding a 1% error for the sample overall.

RECOMMENDATIONS

Keeping in mind that the goal is to develop an assessment approach that would allow dockside enforcement of legal size limits based on shell dimensions but also allowing the conch to be landed without the shell, it is recommended that the enforcement be based on a minimum operculum length of 2.75 inches (70 mm) (to substitute the minimum shell length of 9 inches) or the presence of fully developed reproductive structures (verge or egg groove). Using the operculum length as an assessment criterion has several advantages:

i) Tt has reduced variability with respect to shell length than do alternative criteria such as weight,
ii) Tt is not subject to variability due to variation in post-capture processing (*e.g.*, degree of cleaning),
iii) Operculum length is easy to define and interpret, and
iv) Being a hard structure it is easy to measure.

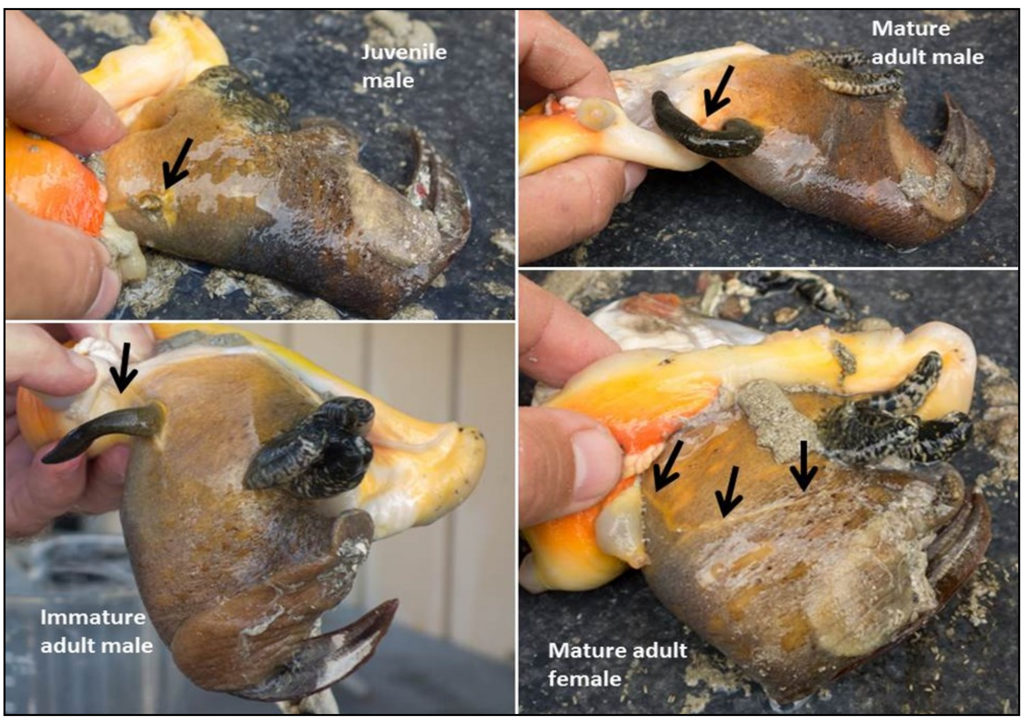

Figure 11. Reproductive structures and stage of maturity in queen conch. *Upper left*: immature male. Verge (arrow) is just starting to develop. In younger males, and in immature females, no structure would be visible. *Lower left*: maturing male. Verge (arrow) has grown, but is still narrow relative to a fully mature male. Verge also usually has a slightly lighter, sometimes greenish color. *Upper right*: mature adult male. Verge (arrow) has thickened and is black in color. *Lower right*: mature adult female. Egg groove (arrows) extends the full length of the mantle and is thick. In immature females the line is absent. In maturing females the line is very thin and does not extend the full length of the mantle.

The presence/absence of fully developed reproductive structures has the advantages that maturity is directly assessed and that it is closely linked to shell lip-thickness. Use of the above criteria additionally requires that all conch must be landed with the operculum and reproductive structures intact and attached.

Nevertheless, there are some trade-offs that must be considered with the recommended approach. For example, the upper left quadrat in Figure 7 represents those conch illegally harvested, but assessed as being legal based on operculum length alone. Most of these, however, represent mature conch that would be assessed as being legal based on reproductive structures. Still, of 72 conch in the upper left quadrant, 15 (21%) would actually be miss-classified by enforcement personnel based on both criteria (operculum length and reproductive structures). Potentially, this leaves a window where fishermen may be tempted to harvest illegal conch thinking that they would be assessed as being legal by enforcement personnel. However, it is not possible to predict if an individual conch would pass this criteria without first measuring its operculum length prior to harvest, but this is difficult and time consuming to do and typically would not be worth a fisher's time.

A final issue is the small percentage of conch that although, legally harvested at above 9 inches would not be assessed as being illegal based on either operculum length and reproductive structures (lower right quadrant in Figure 7). For this reason, it is recommended that a maximum of 10% of the catch can depart from the above size-based criteria. This 10% buffer serves several purposes:

i) It allows for landing of the small percentage of legally caught conch that would otherwise be enforced as being illegal,
ii) It allows for variations due to measurement errors for those conch with sizes near the size limits,
iii) It allows for the natural variability in the relationship between lip-thickness and the development of reproductive structures (Figure 10), and
iv) It allows for error in interpreting if reproductive structures are fully developed.

This last point reflects the reality that enforcement personnel will have to use their judgement in interpreting the degree of development in reproductive structures. This will require that enforcement personnel be specifically trained to recognize these structures and assess their state of development.

Given a 10% buffer, it may at first appear that fishers would be tempted to intentionally illegally harvest 10% of their catch. However, there are several arguments against this scenario. First, the 10% buffer is based on variations that cannot be assessed ahead of time. As a consequence some percentage of assessment errors will occur naturally. If a fisher knowingly harvested illegal conch, this percentage would be added to the naturally occurring rate and cause the percent of conch being assessed as illegal to frequently overshoot the 10% buffer. Second, overall catch rate is still controlled by the daily catch quota (number of conch per person and per boat). Since fishing trips rarely fail to catch the daily limit, knowingly harvesting illegal (generally smaller) conch would only serve to reduce the overall weight of conch meat, which is the measure by which fishers are paid. Thus, given a catch limit, it is in a fisher's interest to limit his catch to the largest individuals possible, which will more likely be legal sized.

As stated above, these recommendations were made with respect to the current regulations in Puerto Rico specifying minimum size using shell dimensions. Thus, this requires no change in the existing law with respect to harvesting conch. However, this does require the use of reproductive structures to assess maturity, and if this is acceptable and practical it opens another, simpler management approach that would aid in maintaining the reproductive stock. This would be to eliminate the minimum shell length requirement and just require all conch to be mature, based on lip-thickness or the presences of reproductive structures. This would have several advantages:

i) All conch would have an opportunity to reproduce,
ii) The largest, most fecund adults would have the same opportunity to reproduce, and
iii) Yield per recruit would be increased, which would translate into greater income for fishers.

Points 1 and 2 would greatly increase the potential reproductive output for conch, which is important given the general low density observed for conch in field surveys, which is well below the level associated with Allee effects (a disproportionate decline in egg production as density declines) observed elsewhere (Stoner and Ray-Culp 2000, Baker et al. 2016). There is now evidence that the implementation of the current minimum shell length and bag limits led to an increase in the proportion of smaller-size conch surviving until adulthood Baker et al. 2016). Allowing all conch to reach maturity should have a similar effect. The tradeoff with this approach would be the *one-time* loss in harvest due to the delay required for those conch that mature at a size greater than 9 inches to reach full maturity. This loss potentially only affects a fraction of the current catch (those not already mature), and the delay might be on the order of 6 to 9 months (Appeldoorn 1988). This one-time loss would then be offset by sustained gains in yield per recruit and hence yield per fishing trip.

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