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Maturation and age in queen conch (*Strombus gigas*): Urgent need for changes in harvest criteria

Allan W. Stoner[a,b,*], Karl W. Mueller[c], Nancy J. Brown-Peterson[d], Martha H. Davis[e], Catherine J. Booker[f]

[a] Community Conch, 3014 NW Sandpiper Circle, Waldport, OR 97394, USA
[b] Fisheries Behavioral Ecology Program, NOAA, National Marine Fisheries Service, Newport, OR 97365, USA
[c] Lummi Natural Resources Department, Lummi Indian Business Council, 2616 Kwina Road, Bellingham, WA 98226, USA
[d] Department of Coastal Sciences, The University of Southern Mississippi, Ocean Springs, MI 39564, USA
[e] Community Conch, 5050 S. Albion Street, Littleton, CO 80121, USA
[f] Community Conch, 304 E 49th Street, Savannah, GA 31405, USA

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ABSTRACT

The queen conch (*Strombus gigas*) is a large economically important gastropod that has been severely depleted throughout much of the Caribbean region. The species has determinate growth and reaches maximum shell length before sexual maturation; thereafter the shell grows only in thickness. In this study, queen conch were collected in the Exuma Cays, Bahamas, to evaluate maturity with respect to shell length (SL) (170–255 mm) and shell lip thickness (LT) (2–42 mm). Soft tissue weight and gonad weight increased with SL, but these same variables, along with the gonadosomatic index (gonad weight/soft tissue weight), all had dome-shaped distributions with LT and decreased slightly with LT > 22 mm. This indicates some loss of fecundity with age; however, no loss of reproductive capability was evident in histological data. Gonad maturity lagged substantially behind first formation of the shell lip. Minimum LT for reproductive maturity was 12 mm for females and 9 mm for males, and 50% maturity for the population was achieved at 26 mm LT for females and 24 mm LT for males, higher than previous estimates. A review of fishing regulations indicates that immature queen conch are being harvested legally in most Caribbean nations, providing at least a partial explanation for widespread depletion. While relationships between shell lip thickness, age, and maturity vary geographically, sustainable management of queen conch will require a minimum shell lip thickness for harvest no less than 15 mm, along with other urgently needed management measures.

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1. Introduction

Sustainable harvest of any exploited species depends upon conserving reproductive stocks. While marine protected areas and harvest quotas are designed to provide for desirable numbers and densities of adults, most fisheries management plans include requirements for minimum size or age at harvest. The importance of large and sexually mature individuals in spawning stocks is evident in studies involving marine fishes (e.g., Berkeley et al., 2004; Froese, 2004; Heupel et al., 2010) and invertebrates (e.g., Perry et al., 1999; Rogers-Bennett et al., 2004; Gorman et al., 2011; Linnane et al., 2011), but regulations for individual species tend to vary among nations. Sometimes the differences are sound, based upon objective biological information, such as differences in age or size at maturity and population modeling. In other cases, harvest-related decisions are based upon best guesses.

Gastropods present certain challenges with respect to criteria for determining sexual maturity. This is because growth is often determinate in gastropods, whereby growth in shell length or weight ends at a time near the onset of sexual maturity (Vermeij, 1980), but size at maturity can be highly variable. Consequently, basic dimensions such as size and weight are not reliable indicators of maturity. Gonadosomatic indices of various forms have been used to determine reproductive maturity and seasonality for a wide range of economically significant gastropods (e.g., Najmudeen, 2007; Cledón et al., 2008; Vasconcelos et al., 2008), but these cannot be determined with living animals. Shell thickness can sometimes be used as an index of sexual maturity because the shell continues to thicken after growth in length or height ends and maturity begins (Appeldoorn, 1988a; Vermeij and Signor, 1992), although various ecological factors such as habitat, food, and presence of predators can also influence shell morphology (e.g., Kemp and Bertness, 1984; Trussell, 2000; Roy, 2002).

* Corresponding author at: Fisheries Behavioral Ecology Program, NOAA, National Marine Fisheries Service, Newport, OR 97365, USA. Tel.: +1 541 867 0165; fax: +1 541 867 0136.
E-mail addresses: allan.stoner@gmail.com, al.stoner@noaa.gov (A.W. Stoner).

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The queen conch (*Strombus gigas*) is a large gastropod (to 30 cm shell length) with high economic and cultural importance, making it iconic throughout most of the Caribbean region (Randall, 1964; Berg and Olsen, 1989). Despite its importance, the queen conch is a good example of a species for which harvest regulations are based upon limited biological information, and those regulations often vary over short distances because of national sovereignties within the region. There is general agreement, however, that no individual should be harvested before it has had the opportunity to reproduce during at least one season. Consequently, most of the Caribbean nations have instituted some minimum shell length or shell lip thickness which reflects queen conch age (Theile, 2005; FAO, 2007). For example, in The Bahamas, legally harvested queen conch must have a flared shell lip (see below), but there is no other size limit. The regulations are more stringent in the United States Virgin Islands and Puerto Rico, where minimum shell length of 9 inches (22.8 cm) and minimum shell lip thickness of 3/8 in. (9.5 mm) are required for harvest (Theile, 2005). Despite attempts to manage the queen conch fisheries, the species continues to be listed in Appendix II of the Convention on International Trade in Endangered Species (CITES) (Daves and Fields, 2004), and numbers continue to decline throughout the geographic range because of ever-increasing fishing pressure (Bell et al., 2005; Posada et al., 2007; Stoner et al., 2012a).

As with many gastropods, growth in queen conch is determinate and strongly influenced by the environment (Alcolado, 1976; Martín-Mora et al., 1995). Queen conch are gonochoristic, the sex ratio is typically 1:1, and individuals reproduce by mating (i.e., fertilization is internal) (Randall, 1964). Approximately 3.5 years after larvae settle to the benthic environment, queen conch reach terminal shell length, and maximum shell length ranges from 140 to 300 mm (Randall, 1964; Appeldoorn, 1988a). At about this time, the outer edge of the shell lip turns outward to form the characteristic flared lip of the "adult" form. Subsequent growth of the shell occurs only in thickness (i.e., not length) and tagging studies show that shell lip thickness provides a relative index for age (Appeldoorn, 1988a, Stoner and Sandt, 1992). Because of these growth characteristics, shell length alone provides no real information about whether or not a queen conch is sexually mature. A flared shell lip indicates a minimum age of 3.5 years, but there have been repeated reminders over the last two decades that a lip flare may not provide ample protection for reproduction. For example, at least some queen conch become mature with relatively thin shell lips (<7 mm) (Egan, 1985; Appeldoorn, 1988a) but recent studies indicate that maturity in many locations occurs at a later time (Avila-Poveda and Baqueiro-Cárdenas, 2006; Bissada, 2011).

This study was conducted to provide a detailed analysis of the relationships between queen conch length, shell lip thickness, and reproductive maturity in the Exuma Cays, Bahamas. Two primary approaches were explored to evaluate maturity over a wide range of shell size and shell lip thickness: (1) a gonadosomatic index (GSI) based upon gonad weight and (2) histological evaluation of ovarian and testicular tissues. The overarching goal was to determine whether a minimum shell lip thickness for sexual maturity could be identified and whether or not the oldest queen conch, those with very thick shell lips, might be reproductively senescent. Our findings are discussed in light of current fishery management strategies in The Bahamas and the greater Caribbean region.

2. Methods

2.1. Study sites and queen conch collections

Queen conch for this project were collected near Lee Stocking Island (23°46′N, 76°06′W) and Warderick Wells (24°23′N, 76°38′W) in the Exuma Cays, The Bahamas. Both sites have well-studied populations of both juvenile and adult queen conch (Stoner and Ray, 1996; Stoner et al., 1998; Stoner, 2003), and the reproductive behavior of these populations is known (Stoner et al., 1992; Stoner and Ray-Culp, 2000). An initial collection of 42 queen conch with flared shell lips were made opportunistically near Lee Stocking Island and Warderick Wells to perfect dissections and develop a GSI for maturing males and females. This was followed by a larger collection (n = 102) near Warderick Wells from which all of the histological samples were taken. The latter site, in the center of the Exuma Cays Land and Sea Park (a no-take fishery reserve), allowed the best opportunity to select queen conch for the shell criteria desired. The samples were collected in depths 2–30 m on sand, hard-bottom, and seagrass (*Thalassia testudinum*) habitats known to be important for queen conch reproduction.

Queen conch collections were made during peak reproductive season (Stoner et al., 1992) to ensure that the individuals collected would have fully developed gonads. Collections were made at Lee Stocking Island 16–26 June 2011, and at Warderick Wells 7–16 July 2011. To explore the relationship between shell lip thickness (i.e., queen conch age) and sexual maturity, an effort was made at the latter site to collect six females and six males in each of nine lip thickness intervals between 0 and 45 mm. The gender of a living queen conch can be determined underwater by turning the shell aperture up and noting the presence or absence of a verge (penis) when the animal emerges to right itself. This allowed only the necessary number of queen conch to be sacrificed for the analysis. The animals were transported to a temporary laboratory on land for processing.

2.2. Measurements and development of the gonadosomatic index

Several morphological measurements were made for each queen conch. Total shell length (SL, mm), was measured from the anterior end of the siphonal canal to the end of the shell spire with large Vernier calipers. Shell lip thickness (LT, mm) was measured with small calipers on the flared outer lip of the posterior half of the shell aperture following the method of Appeldoorn (1988a).

Measures of soft-tissue parts were made after the animal was anesthetized by chilling in a refrigerator (~5 °C) for at least one hour. Removal of the soft tissue was done with care because the gonad runs along the length of the terminal part of the body deep inside the shell spire (see Little, 1965; Reed, 1995a,b). This was achieved by carefully chipping the spire off the shell with a small hatchet, and then pulling the queen conch out through the opening. Once removed from the shell, the gender of the conch was determined based upon the presence of a verge (male) or egg groove which runs along the foot (female), and the total weight of the soft tissue (g) (i.e., all tissues except the shell) was determined with a spring balance.

Dissecting the queen conch gonad is complicated by its anatomy. In both females and males the anterior half of the gonad adheres to the stomach, the posterior half tightly saddles the digestive gland, and lateral skirts of the posterior section form an interlaced connection with the digestive gland. As described above, initial collections of queen conch with flared shell lips were used to perfect and streamline the determination of gonad weight. For each individual, the gonad was excised along its margin with the stomach and digestive gland. This material, weighed to the nearest 0.01 g was called the 'coarse' gonad weight. However, this coarse weight includes a small but difficult-to-remove wedge of digestive gland between the gonadal skirts in the posterior half of the gonad. To obtain a 'clean' gonad weight, the glandular tissue was removed by careful cutting and scraping; this material was weighed (0.01 g), and subtracted from the coarse gonad weight. On average, the residual digestive gland comprised 19% of coarse gonad weight. As expected, this