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AQUACULTURE OF FLORIDA FIGHTING CONCH

Aquaculture of Florida Fighting Conch for Seafood and Aquarium Markets

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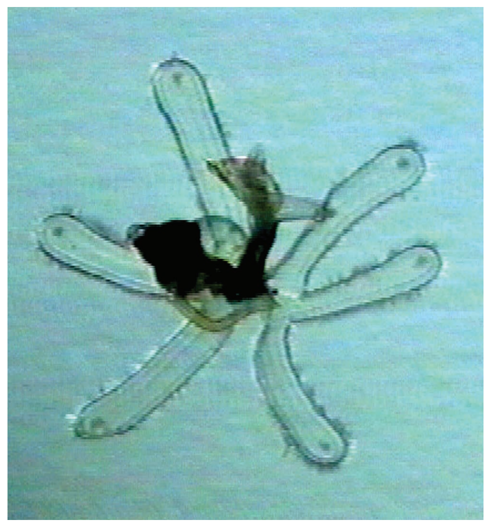
Overview

The fighting conch *Strombus alatus* (Linné, 1758) is found on Florida's Atlantic and Gulf coasts (Perry and Larsen 2004). This medium sized (7-10 cm shell length) herbivorous gastropod (Fig. 1) breeds in shallow waters in seagrass beds, typically during summer, when they form spawning aggregations. They are closely related to the popular commercial fisheries species queen conch *Strombus gigas* (Fig. 2). Both species have similar characteristics in terms of biology, development, taste and meat appearance (Davis and Shawl 2005, O'Dea *et al*. 2014).

Fighting conch has been a subsistence food source among coastal people of the Caribbean and Gulf of Mexico (O'Dea *et al*. 2014) but it has potential to be a suitable species to supplement the queen conch food market if it can be grown in sufficient quantity by the aquaculture industry. This species has qualities that make it a good candidate for seafood aquaculture and aquarium markets (Davis and Shawl 2005).

In the 2000s, fighting conch were successfully cultured in large numbers (50,000-100,000 per year) for the aquarium trade at Harbor Branch Oceanographic Institute (HBOI) based on techniques used to culture queen conch (Davis 2005, Davis and Shawl 2005). Florida fighting conch breeds in captivity, grows fast, is tolerant of variable water quality and is not a protected CITES species like queen conch (Shawl and Davis 2004, Davis and Shawl 2005, Shawl *et al*. 2005).

FIGURE 1. *Adult Florida fighting conch* Strombus alatus. *Photo: Tom Smoyer.*



LEFT, FIGURE 2. *Queen conch* Strombus gigas. *Photo: Megan Davis.* RIGHT, FIGURE 3. *Florida fighting conch veliger larvae with six lobes. Dots on the ends of lobes are characteristic of fighting conch veligers. This veliger is approximately 21 days old and competent for metamorphosis. Photo: Megan Davis.*

Reproduction and Development

Adult conch have separate sexes and internal fertilization. Females of the *Strombus* genus usually copulate with several males in the wild and females are capable of storing sperm for several weeks (Bradshaw-Hawkins and Sander 1981, D'Asaro 1965). Females lay crescent-shaped, sand-covered egg masses that, depending on the *Strombus* species, can contain 76,000 to 485,000 eggs that hatch in three to four days (Shawl and Davis 2004). Free-swimming veliger larvae develop for two to three weeks while feeding on phytoplankton (Fig. 3). After metamorphosis, the now benthic (1.2 mm shell length) snails grow their shells and body mass. Once the "lip" of the conch flares, they will cease growing in shell length, begin to thicken their lip and become sexually mature, which can be one to two years for fighting conch (Davis pers. obs.) to four years for queen conch (Davis 2005).

Conch egg masses in the wild can sometimes be difficult to find, so establishing a captive breeding program in the laboratory or in an enclosure in the wild can be a solution to guarantee reliable egg production (Davis *et al*. 1984, Shawl *et al*. 2005). Several species of the *Strombus* genus, including queen conch (*S. gigas*), Florida fighting conch (*S. alatus*), milk conch (*S. costatus*) and hawk-wing conch (*S. raninus*), have mated and produced egg masses in captivity in a recirculating system at HBOI (Shawl and Davis 2004). Larvae from these captive-laid egg masses were cultured through the juvenile stage. A follow-on study conducted at HBOI looked at reproductive output of Florida fighting conch stocked at different sex

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ratios of males to females (1:1 and 1:2) and and fed different gel diets (koi chow and catfish chow) in a recirculating system and found no differences in egg mass production and in veliger development between treatments (Gillette 2003).

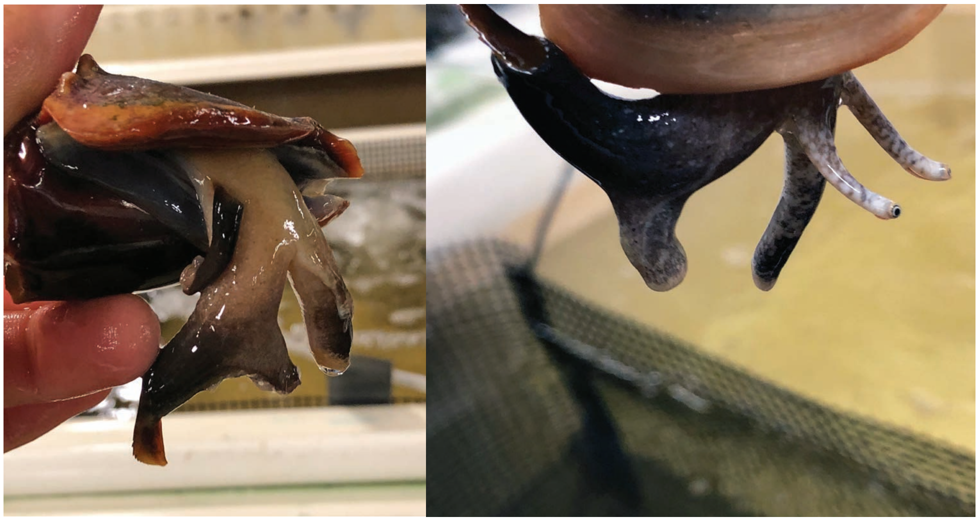

FIGURE 4. *Adult Florida fighting conch reproductive organs: (left) male with black verge, and (right) female with egg groove running the length of the foot. Photos: Megan Davis.*

HBOI has been operating a land-based Integrated Multi-Trophic Aquaculture (IMTA) system since 2012. In this system, culture of fed organisms (finfish and shrimp) is combined with culture of organisms that extract dissolved inorganic nutrients (seaweeds) or particulate organic matter (urchins, sea cucumbers, shellfish) and, hence, the biological and chemical processes at work are in balance (Wills *et al*. 2012, Laramore *et al*. 2018). There have been no studies that have examined Florida fighting conch as an extractive species in an IMTA system. Therefore, HBOI's IMTA system was used for a four-week (20 June – 17 July 2019) fighting conch captive breeding study to determine the effects of sex ratio on reproductive output and to observe behavior of the species in this system.

FIGURE 5. *Adult Florida fighting conch numbered for the study with colored nail polish, blue for males and pink for females. Photo: Megan Davis.*

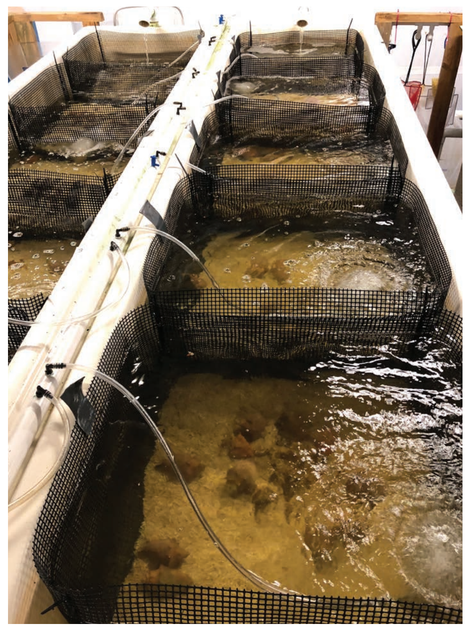

FIGURE 6. *Two study tanks with five baskets per tank. Photo: Megan Davis.*

Florida Fighting Conch Captive Breeding Study Methods

One hundred adult fighting conch were collected from the Florida Keys by Florida Keys Marine Life LLC and shipped overnight to HBOI. Upon arrival mean seawater temperatures in the shipping bags and the IMTA tanks were 25 C and 28 C, respectively. Thus, conch did not require acclimation with this minimal temperature difference. As a quarantine measure, conch were dipped in fresh water for five seconds prior to stocking in tanks. Conch were sexed and their shell lengths (SL) determined with calipers to the nearest millimeter. Sex was determined by holding conch with their aperture facing down and reproductive organs were observed when they emerged partially from their shell. The male has a verge and the female has an egg groove (Fig. 4). For identification purposes, each conch was numbered with fluorescent nail polish, blue for males and pink for females (Fig. 5).

Conch were transferred to two fiberglass study tanks (0.64 m wide × 3.1 m long). Each tank was divided into five equal sections using 0.32-m^2 polypropylene baskets with a mesh of 6 mm and window screen secured on the bottom (Fig. 6). They were elevated from the tank bottom using ½-in PVC pipes. A 1-2 cm deep layer of coarse aragonite crushed coral sand substrate (1-3 mm diameter, Carib Sea) was placed on top of the window screen of the baskets. The sand provided substrate for the broodstock to lay egg masses and also served as additional biofilter for the system. Water depth above the substrate was 15-17 cm.

Study tanks received recirculated seawater from a centralized filtration system that delivered water to various components of the IMTA system (Laramore *et al*. 2018). Seawater entered each basket through a small hose (6-mm diameter) and aeration was provided with one air diffuser per basket. The water turnover rate for each tank was 12 times per day at a flow rate of 0.6 L/min per basket. Water drained through a 2-in diameter standpipe at the end of each tank and then recirculated to the IMTA system. The tank bottom and sand were

FIGURE 7. *Gel diet for adult Florida fighting conch. Photo: Megan Davis.*

FIGURE 8. *Florida fighting conch actively grazed on settled biofloc from the IMTA. Photo: Megan Davis.*

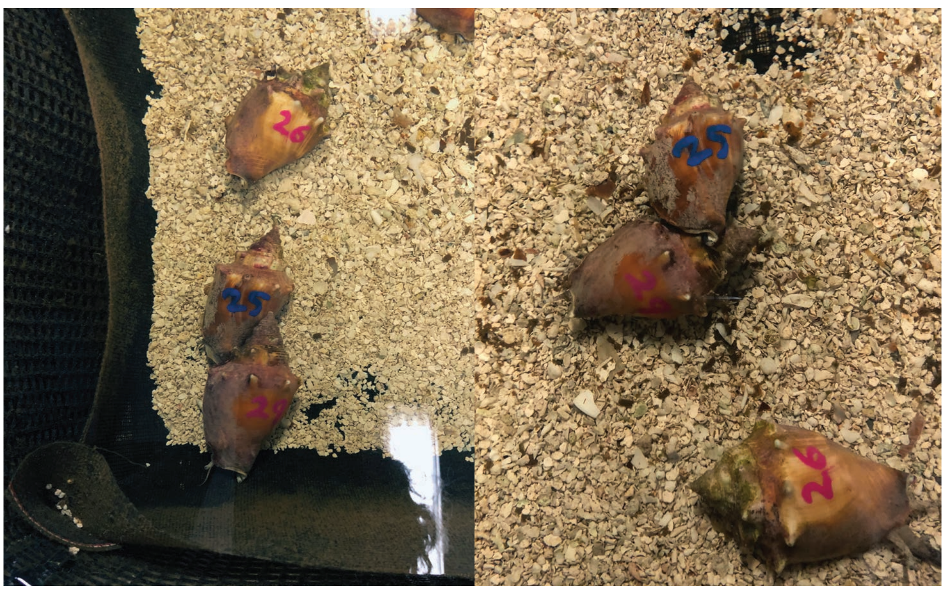

FIGURE 9. *Florida fighting conch mating positions for copulation and internal fertilization: (left) male 25 behind female 29 and (right) male 25 with shell and propodium on female 29. Photos: Megan Davis.*

siphoned once per week to remove feces and settled bioflocs from the IMTA system.

Of the 100 conch delivered to HBOI, only 18 were males. Therefore, 60 fighting conch (18 males and 42 females) were stocked at two sex ratio treatments: 1 male with 5 females (1:5; n=6 replicates) and 3 males with 3 females (3:3; n= 4 replicates). These replicates were randomized among ten baskets in two tanks. The density was six conch per basket, equivalent to 18.5 conch per m^2.

Conch were fed to satiation (approximately 1.5 g per individual) once per day with a benthic gel diet that consisted of 31 percent blended koi chow, 43 percent dry flakes of *Ulva lactuca* that was collected fresh from the IMTA system, 4 percent pork skin gelatin, and 5 percent hot fresh water (Gillette 2003, Shawl and Davis 2004, C. Robinson pers. comm.). The mixture was spread out on aluminum trays to set overnight in a refrigerator (4 C), after which it was cut into pieces and stored in a freezer (-20 C) (Fig. 7). In addition to the prepared diet, conch fed on settled bioflocs that naturally entered tanks from the IMTA system (Fig. 8).

Observations were made daily and egg mass laying and matings were recorded. A mating was considered each time a male was positioned behind and partially on top of a female, or with the male's propodium touching the shell lip of the female (Fig. 9). Egg masses were removed by hand, placed into small containers with seawater and characterized (Fig. 10). Volume displacement of each egg mass was measured with a 100-mL graduated cylinder filled with 50 mL of seawater. For each egg mass the number of eggs per millimeter of strand was counted (n = 5) using a stereomicroscope (40×) equipped with a eye-piece micrometer.

To estimate the number of eggs per egg mass, a correlation between egg mass volume and number of eggs was determined using three small subsamples from ten egg masses (n=31). These subsamples were equivalent to approximately 1 mL of displacement in a 10 mL graduated cylinder that was filled with 5 mL of seawater. The exact displacement volume of each subsample ranged from 0.8 to 1.1 mL (Fig. 11). Each subsample of egg strand was uncoiled and their length (mm) measured with a ruler (Fig. 12). The mean length of the egg strand (n=25) was multiplied by the mean number of eggs per millimeter of egg strand (n=50) to calculate the mean number of eggs per equivalent 1 mL subsample. The strength of correlation was tested with one-way ANOVA with a post-hoc Tukey HSD test ($p < 0.05$).

Water quality parameters were measured on the IMTA seawater that entered the study tanks. Temperature, salinity, and pH values were determined daily. Total ammonia nitrogen (TAN), nitrite, and alkalinity were measured three times per week. Tanks were located within a metal greenhouse with continuous illumination (32 W). Starting on July 9, tanks were covered from 5:00 PM to 8:00 AM to provide the conch a period of darkness. All statistical tests were run in the R studio software (RStudio Team 2015).

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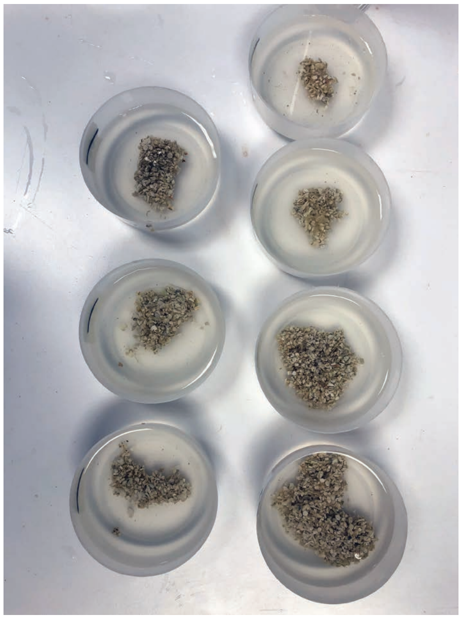

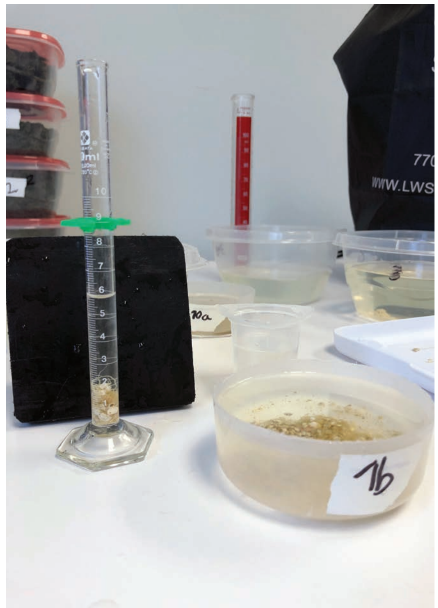

LEFT, FIGURE 10. *Different size egg masses covered in sand from seven Florida fighting conch in the study. Photo: Megan Davis.* MIDDLE, FIGURE 11. *Measuring the displacement volume of a subsample of an egg mass to determine a correlation of egg mass volume with number of eggs per egg mass. Photo: Megan Davis.* RIGHT, FIGURE 12. *Measuring the egg strand length of a 1-mL subsample of the egg mass to determine a correlation of volume with number of egg per millimeter of egg strand. Photo: Megan Davis.*

TABLE 1. Water quality of the IMTA seawater before entering the study tanks (6/20 – 7/17, 2019). Results are expressed as mean + standard devition (n=number of samples) and range for dissolved oxygen.

Parameter	*Results*
Temperature (°C)	29.6 ± 1.0 (60)
pH	7.7 ± 0.2 (60)
Salinity (ppt)	37.5 ± 1.4 (60)
Total Ammonia Nitrogen (mg/L)	0.07 ± 0.07 (12)
Nitrite (mg/L)	0.11 ± 0.03 (12)
Alkalinity CaCO3 (mg/L)	137 ± 10 (12)
Dissolved Oxygen (% saturation)	87.1 - 99.8

Study Results

Except for pH, water quality parameters in this study were within acceptable ranges for conch reproduction (Gillette 2003, Shawl and Davis 2004). Temperature and pH values in the study tanks were statistically different between the morning (lower values) and the late afternoon (higher values). Mean pH value was 7.4±*0.1* in the morning and 8.0±0.3 by late afteroon. Likewise, mean morning temperature (28.8±*1.0* C) increased to a maximum (30.5±1.1 C) by late afternoon. Salinity fluctuated over the course of the study and it was significantly lower in week 1 with mean 35.5±0.6 ppt and was significantly greater in week 3 with mean of 39.1±0.8 ppt (one-way ANOVA, $p<0.05$). Total ammonia nitrogen, nitrite, alkalinity and dissolved oxygen remained relatively constant throughout the study period (Table 1).

The mean shell length of female fighting conch (8.5 ± 0.5 cm; n=42) was significantly greater than that of males (7.9 ± 0.8 cm; n=18) (t-test, $p < 0.05$). All conch survived to the end of the four-week study.

Egg masses were produced over 6-8 hour periods, primarily during the night or early morning hours. Fifty-one egg masses were collected during the study period with 32 from the 1:5 treatment and 19 from the 3:3 treatment. Egg mass production decreased over time in both treatments during the study period (Fig. 13). For both treatments, a greater number of observed matings coincided with a greater production of egg masses during the first two weeks (Fig. 14). Based on daytime observations, there were approximately double the number of matings in the 3:3 treatment (29 observed) compared to the 1:5 treatment (13 observed). However, daily egg mass production, standardized as egg masses per female per day was 0.04 ± 0.05 (n=6) for the 1:5 treatment and 0.06 ± 0.06 (n=4) for the 3:3 treatment, were not statistically different between sex ratio treatments (Kruskal-Wallis test, $p < 0.05$). The number of egg masses per female per week ranged from 0.03-0.80 for the 1:5 treatment and 0.08-1.10 for the 3:3 treatment, with the greatest productivity during the first two weeks of the study (Table 2).

Egg mass data, including egg mass volume, number of eggs per mm of egg strand and number of eggs per egg mass is summarized in Table 3. Egg mass volume varied between 3-19 mL. The mean volume of the egg masses was 9.5 ± 2.5 mL for the 1:5 treatment and 7.6 ± 3.1 mL for the 3:3 treatment and there were no statistical differences between treatments (Kruskal-Wallis test, $p < 0.05$) (Fig. 15). The relationship between eggs per egg mass (y) and egg mass volume (x) can be expressed as $y = 13775\,x - (1 \times 10^{-10})$ (Fig. 16).

Discussion

This study supports the concept that Florida fighting conch is a promising new marketable species that can be included as a

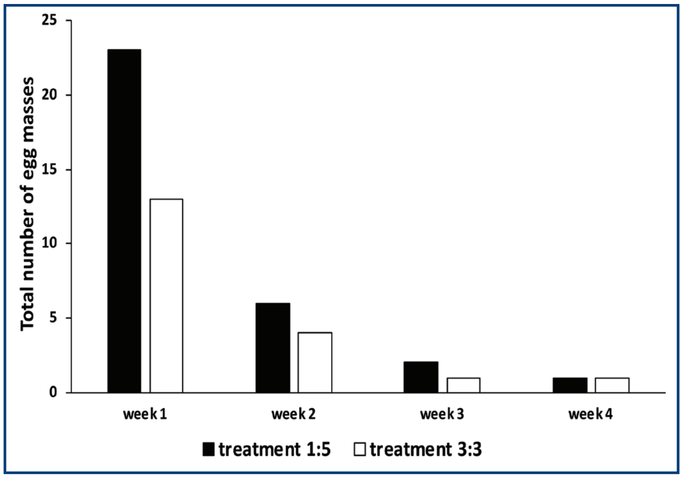

FIGURE 13. *Weekly number of egg masses collected per treatment during the four-week study.*

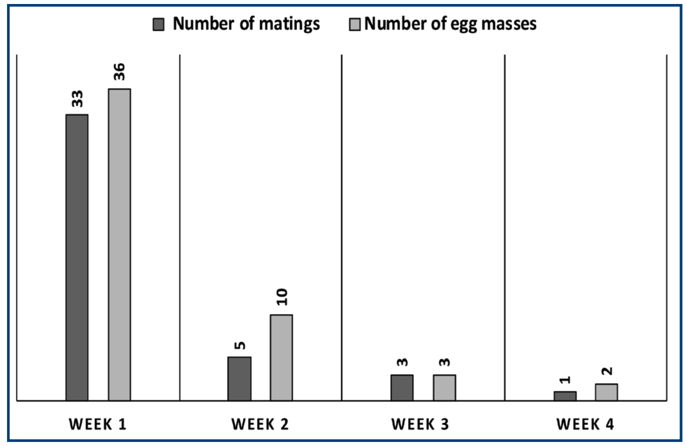

FIGURE 14. *Weekly number of conch egg masses collected for both treatements combined compared with the number of observed daytime matings during the four-week study.*

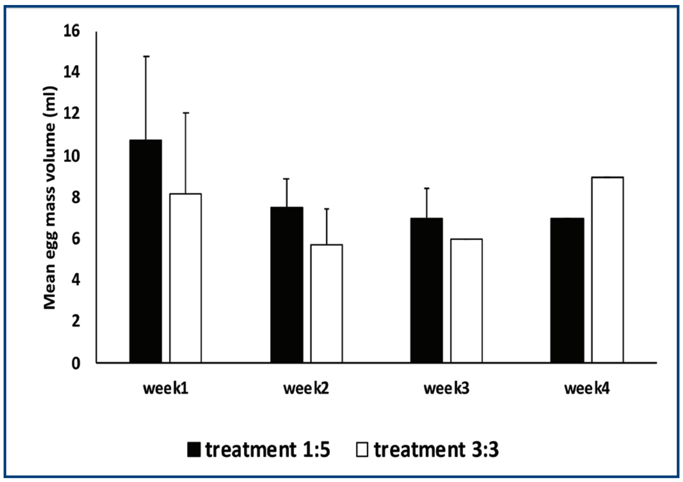

FIGURE 15. *The effect of sex ratio on mean (+ SD) volume of egg mass per treatment during the four-week study.*

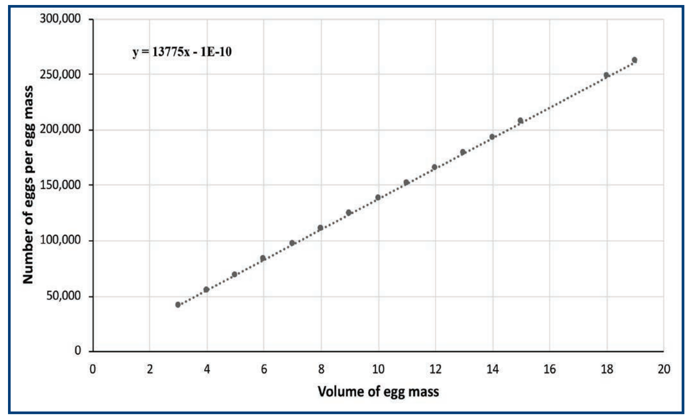

FIGURE 16. *Correlation between the number of eggs per egg mass (y) and volume (mL) of egg mass (x). The values are determined by independent methods (see text).*

species in stand-alone aquaculture systems as well as in IMTA systems. Conch successfully mated and spawned in captivity in the HBOI IMTA system. Results of this study supported previous results indicating that adults can be stocked at higher female to male ratio without loss of female productivity in regards to the number of egg masses and number of eggs produced per female per week (Gillette 2003). Stocking females at a higher sex ratio (2 to 5 females per male) may also alleviate male guarding and sparring (see sidebar). In this study, variation in sizes of egg masses laid were not different between the two sex ratio treatments (3-19 ml volume displacement). This variation resulted in a broader range of estimated number of eggs per egg mass (41,000-262,000; n=50) compared to a previous study where the range was 76,000-182,000 (n=10) (Shawl and Davis 2004). These range differences were likely due to the number of egg masses sampled or variation of the sizes of egg masses found in each study. Gillette (2003) also showed variation in sizes of egg mass based on measurements of length × width × height (0.48–33 cm^3), however, the number of eggs per egg mass was not determined.

Egg mass output of Florida fighting conch will vary based on factors such as type of system, stocking density, when conch were placed in the study, matings, and a host of environmental parameters. Cleanliness of the sand substrate in this study also appeared to play a role in egg laying frequency. When sand was siphon-cleaned, egg laying resumed the following day. The mean number of egg masses laid per female per week in this study was lower (0.30 egg masses) compared to 0.56 for Shawl and Davis (2004), but was higher than the 0.10 for Gillette (2003).

Females maintained higher egg mass productivity during the first two weeks of the study. Fighting conch store sperm over prolonged periods (Bradshaw-Hawkins and Sander 1981, D'Asaro 1965) and tend to lay a higher number of eggs in captivity after handling from transport (seen in this study and Shawl and Davis 2004). This production peak needs to be taken into consideration when planning a breeding program. In the Gillette (2003) study conch were placed in the study seven weeks after collection and this might explain the lower number of egg masses per female per week.

During the last two weeks of the study there was a decrease in female productivity and some egg masses were observed to have egg capsules and portions of egg strands were empty, indicating lack of fertilization. Based on this study and previous studies with conch reproduction in captivity and in the field, pH,

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TABLE 2. Weekly egg mass production per treatment during the four week study. The egg mass production was standardized as egg masses per female per week per treatment. Results are expressed as mean ± standard deviation (n=number of egg masses).

Treatment	*Week 1 (6/21-6/27)*	*Week 2 (6/28-7/4)*	*Week 3 (7/5-7/11)*	*Week4 (7/12-7/17)*
1:5	0.8 ± 0.4 (23)	0.2 ± 0.2 (6)	0.07 ± 0.10 (2)	0.03 ± 0.08 (1)
3:3	1.1 ± 0.5 (13)	0.3 ± 0.4 (4)	0.08 ± 0.17 (1)	0.08 ± 0.17 (1)

TABLE 3. Summary of egg mass data from the study. Results are expressed as mean ± standard deviation (n = samples) and ranges.

Variable	*Results*
Volume of egg mass (mL)	8.8 ± 3.6 (50) 3 - 19
Number of eggs per mm of egg mass strand	12.0 ± 1.4 (51) 9.6 - 15.0
Length of uncoiled egg strand in an equivalent 1 ml egg mass subsample (mm)	1,144 ± 309 (25) 588 - 1885
Calculated number of eggs per 1 mL egg mass subsample	13,775
Calculated number of eggs per egg mass	120,943 ± 49,727 (50) 41,324 - 261,721

temperature and light affect gamete output and egg mass quality (Davis *et al*. 1984, Shawl and Davis 2004). Except for pH, water quality parameters in this study were within the acceptable range for conch reproduction (Shawl and Davis 2004).

The mean pH of 8.0 during the daytime was similar to pH values in natural habitats but low pH values (fluctuated from 7.1–7.7) are low in comparison to pH values of ~8.1 for surface ocean water. This low pH may be due to the HBOI IMTA system water recirculating through the seaweed culture at night when increased respiration produces carbon dioxide that lowers pH. Ocean acidification studies have shown that low pH has an adverse effect on molluscan development (Ross *et al*. 2011). In a previous fighting conch breeding study at HBOI, mean pH was 7.8 in the recirculating system and egg production did not slow down towards the end of the six-week period and veliger development was successful (Gillette 2003). The effect of lower pH and possible other water quality conditions on conch female productivity and egg viability needs to be addressed in future IMTA studies.

This study added new knowledge for the aquaculture of the Florida fighting conch such as the establishment of captive breeding program in an IMTA system with the use of a sex ratio skewed toward females. An additional benefit of using the IMTA system is the potential savings on feed costs because the conch in this study were observed actively grazing on bioflocs in their tanks that was produced in other components of the IMTA system. This makes the fighting conch an ideal extractive species for the IMTA system.

When the findings from this study are combined with results from previous studies, a scenario to produce approximately one million eggs per week (eight egg masses per week) would be possible using a sex ratio of two females (84 females) to one male (42 total). This would be an adequate amount of eggs for an efficient production of the Florida fighting conch in an aquaculture facility that was sized according to product needs.

Now that this desirable species can be cultured through all developmental phases in captivity (this study, Gillette 2003, Shawl and Davis 2004, Davis and Shawl 2005, Shawl *et al*. 2005) potential commercial markets for the seafood and aquarium trade need to be explored. Fighting conch will reach 6 cm shell length in about 8-10 months and could be sold as a seafood product called Ocean Escargot (Fig. 17). It also has potential to help supplement queen conch delicacies such as conch fritters, salad and chowder. In four to five months, conch grow to 3 cm shell length and could be sold as grazers for the aquarium trade, which has been accomplished previously with this species (Shawl and Spring 2003, Davis and Shawl 2005) (Fig. 18). Development of commercial production of Florida fighting conch would provide a new product for the aquaculture industry to grow and sell.

FIGURE 17. *Cultured juvenile Florida fighting conch for potential seafood markets (6 cm shell length). Photo: Tom Smoyer.*

FIGURE 18. *Cultured juvenile Florida fighting conch for the aquarium trade (3 cm shell length). Photo: Tom Smoyer.*

Why are They Called Fighting Conch?

Florida fighting conch have similar characteristics to queen conch in relation to sexual morphology, internal fertilization and egg mass laying. However, the Florida fighting conch demonstrates mating behavior unique to the species. Males will often guard an egg-laying female or copulating female and will challenge any male that attempts to mate with her. The challenge occurs in the form of a jousting tournament, with each combatant using their proboscis, or one male will use their shell to push another male away, hence the name "fighting" conch.

Notes

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