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CONCH AQUACULTURE IN PUERTO RICO

Understanding How to Operate a Conch Nursery Recirculating Aquaculture System in Puerto Rico

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Introduction

The queen conch *Aliger gigas*, formerly known as *Strombus gigas*, is an important fishery stock for Puerto Rico and the Caribbean region (Fig. 1). However, intensive fishing and habitat degradation have caused conch populations to dwindle significantly. Known as *carrucho* in Puerto Rico, the queen conch is popularly consumed on the island and so low quantities are exported (Davis and Espinoza 2020). For the artisanal fishery, Puerto Rico has management regulations in place as part of the Queen Conch Resources Fishery Management Plan. These regulations include a minimum harvest size of 22.9 cm for shell length and 9.5 mm for lip thickness, daily bag limits of 150 conch/fisher for licensed commercial fishers and for vessels of 300 conch/vessel, a closed season from August 1 to October 31 and a prohibition of harvest in federal waters out to 16.97 km.

FIGURE 1. *Queen conch* Aliger gigas *an important fishery species and keystone herbivore in seagrass habitats in the Caribbean (Photo: Megan Davis).*

FIGURE 2, LEFT. *Naguabo Fishing Association on Húcares Beach, Puerto Rico, location of the Puerto Rico queen conch hatchery and nursery aquaculture project (Photo: Megan Davis).* FIGURE 3, RIGHT. *Puerto Rico queen conch hatchery for egg mass incubation, and larval, metamorphosis and microalgae culture. Featured in the photo is Victoria Cassar (Hatchery Manager, Conservación ConCiencia) in the front, Raimundo Espinoza (Executive Director, Conservación ConCiencia) in the middle, and Megan Davis (Research Professor, FAU Harbor Branch Oceanographic Institute) in the back (Photo: Leah Biery).*

Intent on aiding the repopulation effort for the queen conch stock in Puerto Rico, a partnership project began in 2019. The partners include Florida Atlantic University Harbor Branch Oceanographic Institute, Conservación ConCiencia (Puerto Rico) and the Naguabo Fishing Association (Puerto Rico). The project, funded by Saltonstall-Kennedy NOAA Fisheries, serves to support creation and operation of a queen conch hatchery and nursery located within facilities owned by the Naguabo Fishing Association (Fig. 2). This community-based project is designed to assist in assuring the development of queen conch from egg to larvae (0.35-1.2 mm), metamorphosis and post-metamorphosis (1.2-4 mm) and juvenile stage (4-80 mm) before release to the ocean (Davis and Cassar 2020, Davis and Espinoza 2020). As juvenile conch grow larger, they are moved from an indoor environment (hatchery) to an outdoor setting (nursery) (Figs. 3 and 4).

The nursery recirculating aquaculture system ensures continual development of juveniles in a larger culture area, while opening up space in the hatchery for newly metamorphosed conch. The nursery system is located under a roof outdoors, implying that there are variables that are less controlled than inside the hatchery. For this reason, understanding the nursery system's operational dynamics, including establishing correct water quality for conch well-

FIGURE 4. *Measuring an adult milk conch* Macrostrombus costatus *that was part of the study (Photo: Megan Davis).*

FIGURE 6. *Each tank has four trays that each receive seawater through a spray-bar manifold (Photo: Chalier Dones-Ortiz).*

being (e.g., pH, temperature, salinity) and a maintenance schedule become important.

This study was done with adult milk conch *Macrostrombus costatus* as a proxy mollusk to the queen conch (Fig. 4). This allowed us to understand idiosyncrasies of the new outdoor seawater nursery recirculating aquaculture system. Likewise, the trial served to fine-tune system design to establish an adequate environment for successful juvenile queen conch rearing and development.

Methods

A multilevel seawater nursery recirculating aquaculture system was built for rearing queen conch juveniles (Fig. 5). The system consists of six rectangular tanks in two stacks with three rectangular tanks per stack. Each fiberglass tank is 232 cm L × 51 cm W × 30 cm H with a surface area of 1.5 m^2 and a volume of 270 L when filled to a water depth of 23 cm, as controlled by a 2-in PVC standpipe. Each tank independently drains through a standpipe into a sump (190 cm L × 77 cm W × 52 cm H) that holds a maximum volume of 360 L of

FIGURE 5. *Nursery recirculating aquaculture system used for the study and designed for growing queen conch juveniles (Photo: Chalier Dones-Ortiz).*

seawater, approximately 25 percent of total system volume (1,613 L). Two submersible pumps (Danner Supreme Magnetic Drive Pump, Model MD92) were selected based on the overall tank system height (2.1 m), idealized flow rate (8 L/min per tank) and tank turnover rate (2×/hr). Each pump was placed in the sump and was designed to lift seawater from the sump to one stack of three tanks.

Each tank has four trays (39 cm L × 46 cm W × 15 cm H) that each receive seawater through a spray-bar manifold, designed to provide circulation to avoid water stagnation (Fig. 6). Trays were built with 1.9-cm thick PVC panels for the walls and a window screen (diagonal 1.25-mm size opening mesh) attached to the bottom. Each tray contains approximately 20 mm of 1-3 mm aragonite sand (CaribSea, Inc.) used as a substrate for conch, physical filter to trap feed and biofilter for the system. To test the system, only the bottom two tanks were used for conch rearing.

Although the system was designed for juvenile queen conch rearing, adult milk conch (n=24) were used to test the nursery system over a 10-wk period (8 December 2021 to 16 February 2022). Adult milk conch collected by Naguabo fishers from different locations on the south coast of Vieques, Puerto Rico were brought to the Naguabo Fishing Association. Once received, sex was determined by holding conch with their aperture facing down, which made it possible to see their reproductive structures as the animal slowly emerged from their shell. Males have a verge located high on the foot and females have a thin egg groove that extends the length of the foot (Fig. 7a, b).

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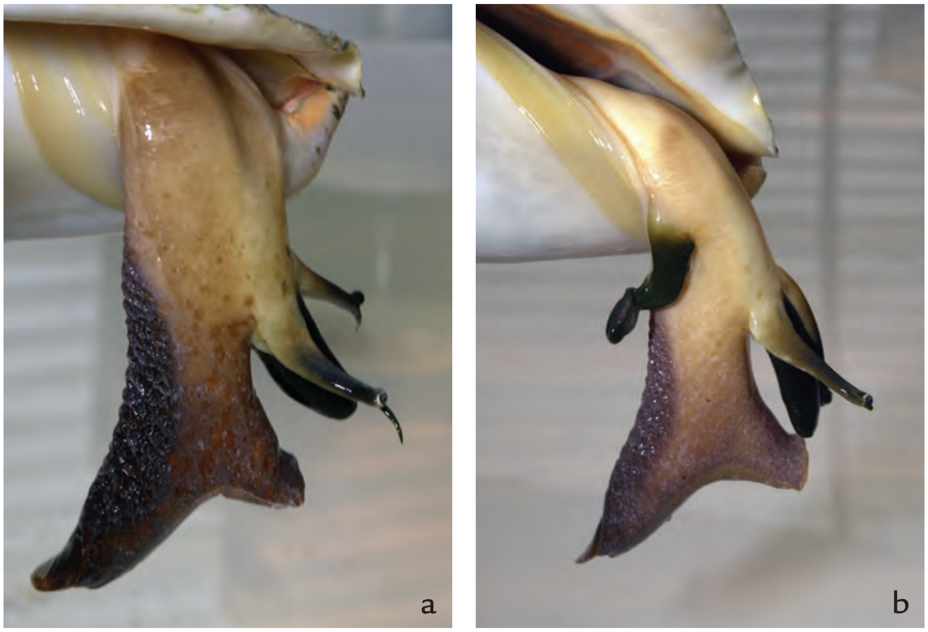

FIGURE 7, LEFT AND MIDDLE. *Milk conch* M. costatus *reproductive organs: female egg groove (a) and male verge (b) (Photo: FAU Harbor Branch).*
FIGURE 8, RIGHT. *Chalier Dones-Ortiz, research intern, marking female conch. Females were marked using pink nail polish with an 'I' or a 'X' to distinguish between females when more than one was in the same tray. Males were not marked (Photo: Victoria Cassar).*

Tanks were labeled A and B and trays in the tank were assigned a number (A1 to A4 and B1 to B4). Each tray was stocked with three milk conch; four trays had two males and one female (Tank A) and four trays had one male and two females (Tank B). To distinguish between sexes, pink nail polish was used to mark females (Fig. 8). If there were more than one female in a tray, 'X' and 'I' symbols were used to differentiate them. To discern between the two males, size differences and shell characteristics were used.

Conch were fed daily with a gel diet consisting of dry *Ulva lactuca* seaweed (12 percent), shrimp pellets (24 percent) and gelatin (4 percent) (Fig. 9a). Solid components were combined in distilled water (60 percent) and heated until boiling. The resulting green paste was poured into aluminum trays and allowed to harden in a refrigerator (Fig. 9b). After hardening, the gel diet was cut into cubes and stored in a freezer. For feeding, gel diet cubes were weighed daily (Fig. 9c) throughout the 10-wk study period. The amount of feed remaining in each tray 24 h after feeding was determined. Minimum and maximum amounts were established (1-6 g) using feed uptake results during the first month of the study.

Two feed placement methods based on grazing behavior were implemented. In one placement (P1), feed was placed in the tray center and conch were placed with their siphonal canal positioned towards the gel diet and each other (Fig. 10a). In the other placement (P2), feed was placed in tray corners and conch were positioned with their siphonal canals toward the feed (Fig. 10b).

In addition to the gel feed, conch diets were supplemented weekly with 3-6 detrital blades of seagrass *Thalassia testudinum* per tray. Seagrass blades, covered with epiphytes, were collected from seagrass meadows near the Naguabo Fishing Association. Conch also fed on natural periphytic algal growth that became established on tray walls.

During the first four weeks of the study, maintenance of sand trays with conch was performed on a three-day cycle. One at a time, each tray was removed with the conch from their respective position in the tanks and placed in a spraying station. A spray bar with pressurized seawater was used to push uneaten feed and feces

TABLE 1. Water quality of integrated nursery system prior and during M. costatus husbandry (12/07/21 – 2/16/22). Results are expressed as mean ± standard deviation (n=number of observations) and range for dissolved oxygen.

Variable	*Ideal*	*Acceptable Range*	*Results*
pH	8.1	7.6 - 8.1	7.8 ± 0.1 (n=10)
Salinity (ppt)	36	28 - 40	39.0 ± 1.5 (n=68)
Temperature AM (C)	28	24 - 30	24.3 ± 0.6 (n=66)
Temperature PM (C)	28	24 - 30	24.7 ± 1.0 (n=68)
Dissolved oxygen (% saturation)	85	80 - 90	80.9 - 86.8 (n=2)

FIGURE 9. *Ingredients of the gel-diet include from top to bottom (a) dried and blended Ulva, gelatin and shrimp feed pellets ground and dissolved in water, (b) mixing the ingredients with hot distilled water, (c) cutting gel-diet cubes, (d) weighing frozen gel-diet cubes to feed milk conch (Photos: a, b, c – Megan Davis; d – Chalier Dones-Ortiz).*

trapped in the sand into a spraying station container (Fig. 11a). With the tray still in the spraying station, debris and the minimal amount of sand that fell through the tray screen was vacuumed off the tank bottom with a PVC pipe siphon into 5-gal (19-L) buckets (Fig. 11b). After siphoning, heavier particles were allowed to settle in buckets (Fig. 11c). Then, seawater in buckets was carefully decanted and returned to the sump, avoiding the re-introduction of debris. Nutrient-rich debris from tray spraying was disposed of due to the heavy concentration of organics, which could have been detrimental to the

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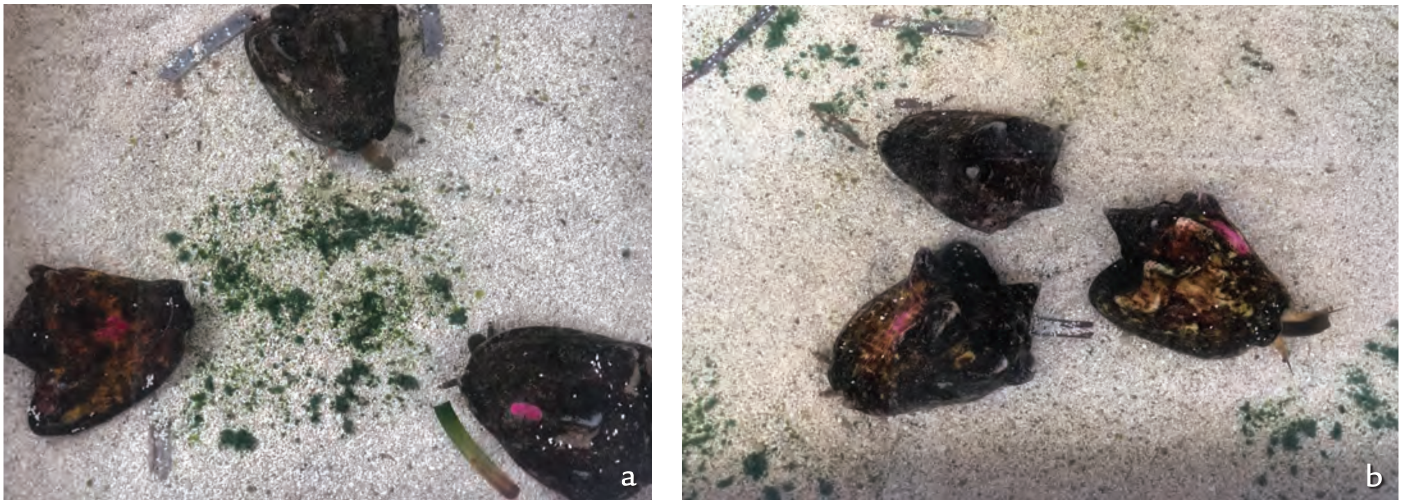


FIGURE 10. *(a) Gel-diet placed in center of tray with conch facing each other (P1) and (b) conch placed in center facing towards the food in tray corners (P2) (Photos: Chalier Dones-Ortiz).*

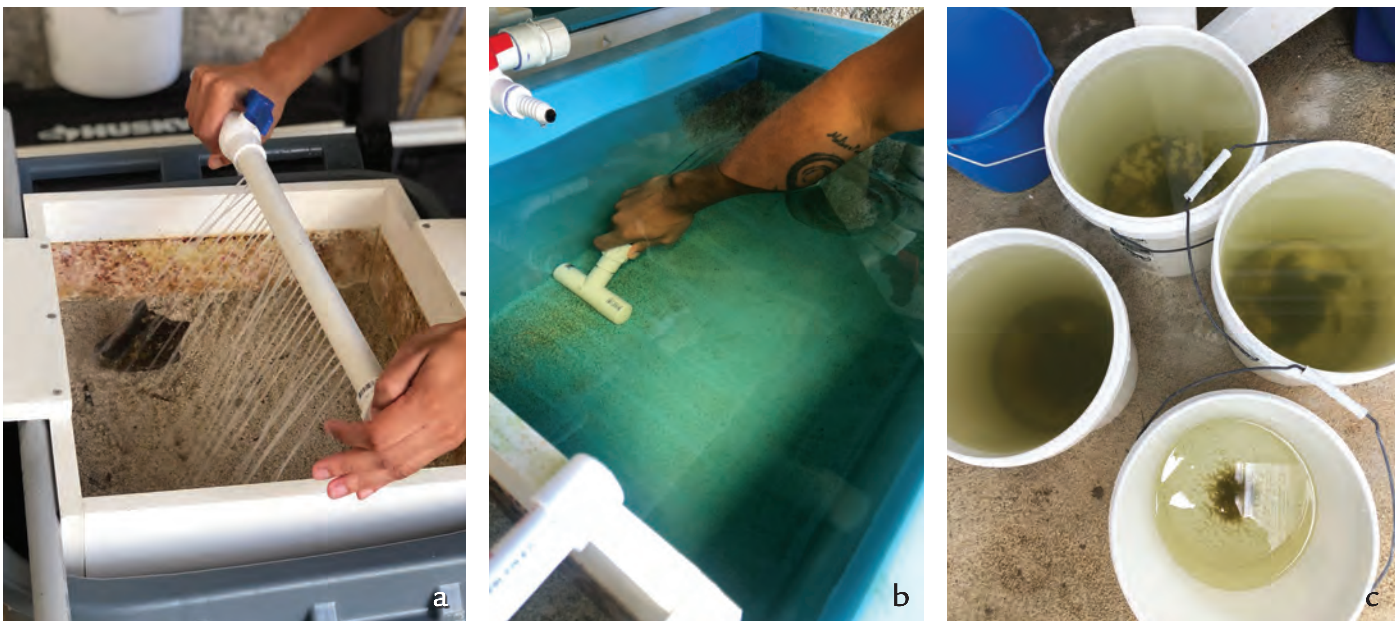


FIGURE 11. *(a) A pressurized spray bar was used to remove feces and any excess feed from the sand substrate in the tray, (b) a siphon was used to remove debris from the bottom of the tank underneath the trays, (c) and debris from tank siphoning was settled and the supernatant was returned to the system (Photos: a, b – Victoria Cassar; c – Megan Davis).*

conch and the system. By the second month, the frequency of the spraying and siphoning cycle was decreased from every three days to once a week. General system maintenance included weekly pump filter cleaning, topping off sump seawater level as needed and a partial water exchange halfway through the study.

Daily observations were made regarding remaining feed, feces in the tray and conch buried in sand. Animal acclimation or welfare monitoring such as active grazing and movement, mucus production that can be a sign of stress, mating and egg laying were recorded. Additionally, water quality parameters were monitored throughout the study. Temperature was measured twice daily (0800 and 1300 h) with an infrared thermometer. Salinity was measured daily with a refractometer. In addition, pH was measured with a pH meter pen and dissolved oxygen concentration was measured with a YSI meter weekly.

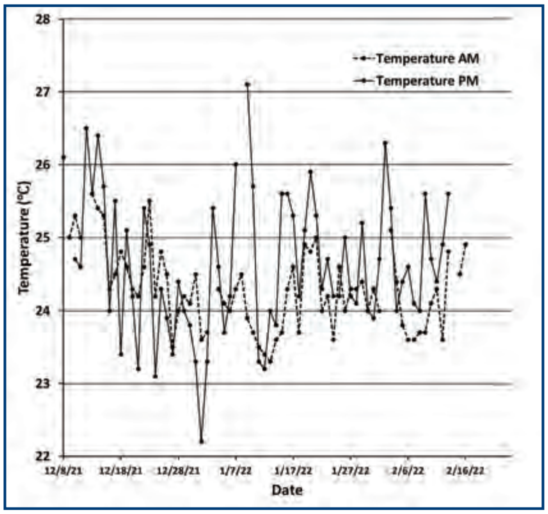
Results and Discussion

During the 10-wk study, water quality, system operation and conch observations were recorded. Apart from salinity, all other water quality parameters remained in acceptable ranges (Table 1). Minimal differences were seen between morning and afternoon mean temperatures and these did not vary greatly (Fig. 12). The acceptable temperature range for growing queen conch is 24-30 C. As the study took place during the winter, temperature in the system was on the lower end of the range. Mean minimum air temperature in coastal areas of Puerto Rico from January to February is 24 C (Gómez 2014). The stability of water temperature in the nursery system could have been due to limited exposure to direct sunlight and the interaction with outside air due to exposure of the open trays with spray bars. Salinity slowly increased over time, starting at 36 ppt at the trial beginning and reaching a maximum of 41 ppt after six weeks (Fig. 13). The outdoor location of the nursery system, with open tanks

TABLE 2. Weekly ranges, based on daily observations of remaining feed and milk conch buried percentages throughout the 10-week study.

	Remaining feed (%)[1]		Burying (%)	
Week	Tank A	Tank B	Tank A	Tank B
1	0 - 40	0 - 50	0 - 100	0 - 66
2	0 - 15	0 - 20	66 - 100	0 - 100
3	0 - 5	0 - 10	33 - 100	0 - 100
4	0 - 15	0 -10	0 - 100	0 - 100
5	0 - 10	0 - 5	0 - 66	0 - 100
6	0 - 10	0 - 5	0 - 100	0 - 66
7	0 - 5	0 - < 5	0 -100	0 - 66
8	0	0 - 5	0 - 100	0 - 66
9	0	0 - 5	0 - 66	0 - 100
10	0	0 - 10	0 - 100	0 - 33

[1] *Remaining feed corresponds to an estimated value based on visual observations.*



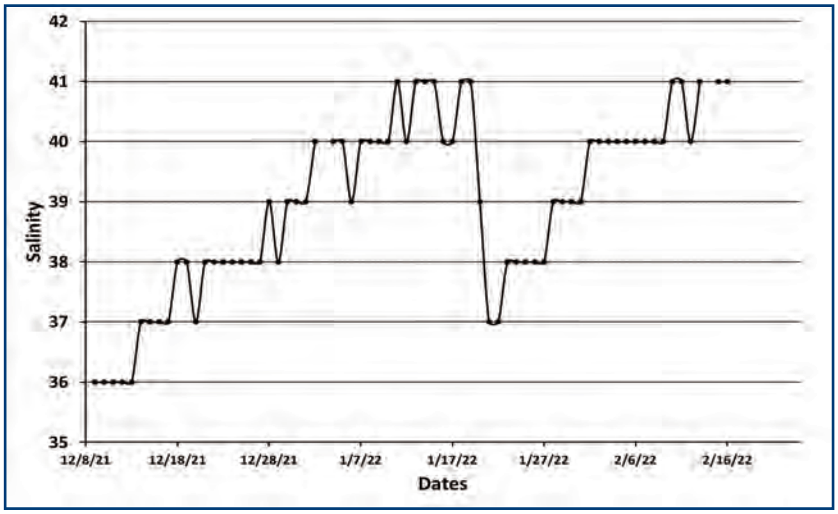


FIGURE 12, LEFT. *Morning and afternoon temperature (C) during the 10-wk trial (December 8, 2021 – February 16, 2022).*
FIGURE 13, RIGHT. *Salinity (ppt) during the 10-wk trial (December 8, 2021 – February 16, 2022).*

and spray bars (Fig. 6), resulted in evaporation that caused salinity to increase over time. To control salinity a partial water change (1/3 of the water volume) was conducted (1/19/21) in the nursery system and this lowered salinity from 41 to 37 ppt. Also, to mediate salinity increase, spray bars were placed lower inside trays. During the study, the pH range was 7.5-7.9 and dissolved oxygen saturation range was 80.9-86.8 percent.

Successful system operation such as spraying trays, siphoning tanks and pump filter cleaning schedules were all determined based on feces accumulation, uneaten feed and animal behavior. For instance, a small amount of excess mucus produced by conch was likely from overfeeding and/or high nutrient debris in the tray environment. Mucus observation and feed remaining were used to adjust the frequency of tray spraying and tank siphoning cycles from every three days to every seven days. On the other hand, filter cleaning on the intake side of the pump did not need to be adjusted and therefore was performed once weekly throughout the study. As the study progressed, there was an increase in the amount of debris trapped on the filter during weekly filter cleanings, likely due to organics accumulating in the system.

All conch observations were made in the morning before feeding or any type of manipulation of animals or the system. Survival rate (= remaining amount of conch/original amount of conch × 100) at the culmination of the study was 92 percent. One mortality was noted for a female 15 days after commencement of the trial, likely due to stress during collection. One male conch was released 39 days after beginning the study due to abnormal behavior such as lack of food grazing, higher than usual mucus production, lethargy to stimuli and receding into its shell. Although the cause of this behavior is unknown, it was unusual and should be monitored. It was not anticipated that adult milk conch would grow during the study because all had flared lips and shell length is terminal after the lip is formed. At the end of the study, shell lengths (cm) of 22 of the original 24 adult milk conch were measured from the apex to the siphonal canal with calipers (Fig. 5). Males had a mean shell length of 9.6 cm

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FIGURE 14. *(a) Puerto Rico hatchery-raised juvenile queen conch (20-40 mm) and (b) on the sand in a nursery system tray (Photos: Megan Davis).*

(n = 11), while females were larger, with a mean shell length of 10.5 cm (n = 11).

At the beginning of the study, to determine if conch were consuming the gel diet, observations of grazing and feces confirmed this activity. Feed amounts varied throughout the study until specific quantities per tray were determined. Feeding rates ranged from 1-6 g/tray and were increased or decreased according to the quantities of feed remaining after 24 h. Low amounts of remaining feed and the presence of feces were considered signs of animal normalcy and well-being. Feed remaining in the morning was estimated daily as the percent remaining. By week 10, the amounts of feed remaining in the four A trays as well as tank B trays decreased and reached 0 percent and 0-5 percent, respectively (Table 2). Thus, established feeding amounts became more refined as the study progressed.

Food placement methods were done arbitrarily at first but later were modified by subjectively assessing tray feeding behaviors using methods P1 or P2 (Fig. 10a, b). As the trial developed, only tray B1 conch received feed placement method 1 (P1) based on their grazing behavior and feed consumption. All other trays of conch were given placement method 2 (P2). Establishing a specific position for the conch meant that the next day we had an idea of how much they had moved, which was an indicator of normal behavior.

The majority of conch activity occurs at night and conch tend to bury during the day if fed to satiation (Davis 2005). In this study, milk conch were active during the day, although they were also observed being still, partially buried or substantially buried. This was interpreted as a sign of normalcy and was not considered a sign of conch malnutrition due to underfeeding. For the whole study, the percentage of buried conch ranged from 0-100 percent for all trays (Table 2).

Contrary to work done by Shawl and Davis (2004), no mating or egg laying events occurred during the 10-wk study. Mean temperatures rangef from 22-25 C, where egg mass laying was found to slow or stop (Shawl and Davis 2004). Sub-optimal temperatures may have played a role in deterring an adequate environment for conch reproduction. Conch density may have also affected spawning activity. The stocking density was 3 milk conch/0.18-m^2 tray, which was far denser than what was used by Shawl and Davis (2004) (1.2 milk conch /10 m^2), where mating and egg laying were recorded.

Conclusion

This study was successful in establishing an understanding of how to operate a conch nursery recirculating aquaculture system and the protocols needed for the effective husbandry of hatchery-reared queen conch juveniles. Ten weeks was sufficient to test the nursery system as it allowed stabilization of water quality, modification of system design (e.g., pump selection, tray spray bars and flow rate) and establishment of biological filtration in sand trays. Adult milk conch were a good proxy mollusk to determine conch rearing techniques that are transferable to culturing juvenile queen conch with assurance of their well-being. At the study end, we stocked the first batches of cultured queen conch juveniles into the system (2/16/22) (Fig.

FIGURE 15, CLOCKWISE FROM LEFT. *(a) Puerto Rico queen conch project team, left to right, Raimundo Espinoza, Conservación ConCiencia Executive Director; Megan Davis, FAU Harbor Branch Research Professor; Victoria Cassar, Hatchery Manager; Marie Garcia, Hatchery Assistant; and Chalier Dones-Ortiz, Research Intern. (b) Carlos Velazquez, President (left) and Julio Ortiz, Treasurer and fisher (right) of the Naguabo Fishing Association. (c) Marcos Espinosa, lead contractor that has been instrumental in building the hatchery and nursey.*

14). These queen conch will be raised for 12 months in the nursery recirculating aquaculture system until 7-8 cm shell length, when they will be released into the ocean for species repopulation.

Acknowledgements

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Notes

Chalier Dones-Ortiz, agronomist, graduate of the Animal Sciences Department in the University of Puerto Rico, Mayagüez (2020). Chalier was an intern for the Puerto Rico queen conch aquaculture project located at the Naguabo Fishing Association from 15 November 2021 to 4 March 2022.

Megan Davis, Ph.D. is a research professor in the Aquaculture and Stock Enhancement Program at Florida Atlantic University Harbor Branch Oceanographic Institute. She is Principal Investigator for the Puerto Rico queen conch aquaculture project and provided mentorship for Chalier Dones-Ortiz during his internship.

Raimundo Espinoza is the Executive Director of Conservación ConCiencia located in San Juan, Puerto Rico. He is Co-Principal Investigator for the Puerto Rico queen conch aquaculture project and provided mentorship for Chalier Dones-Ortiz during his internship.

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