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The effect of stocking density and diet on the growth and survival of cultured Florida apple snails, *Pomacea paludosa*

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ABSTRACT

There has been interest in culturing the Florida apple snail, *Pomacea paludosa*, for stock enhancement purposes in central and south Florida to help promote snail kite (*Rostramus sociabilis*) recovery. In 2007, Harbor Branch Oceanographic Institute at Florida Atlantic University began to research techniques necessary to culture Florida apple snails at a commercial scale (tens of thousands per year). This article reviews stocking density and diet experiments that have yielded a protocol for large-scale culture of Florida apple snails. The objectives of this research were to determine the stocking density that supports efficient production and to determine whether diet choice affects growth and survival and can improve captive growth rates at higher stocking densities. Juvenile apple snails were stocked at six densities (10, 20, 40, 60, 80, and 100 snails/m^2) in recirculating aquaculture systems with a raised substrate. Although growth was faster in the lowest stocking density compared to the highest density during the first month, the difference subsided in the second month, and overall growth rates and final shell lengths were not statistically different. Survival was not affected by density. A second experiment testing higher densities (100, 175, and 250 snails/m^2) showed that snails could be stocked as high as 250 snails/m^2 and confirmed that the lowest density is optimal for first-month growth. An initial diet study examining six diets (romaine lettuce, two combination diets of plant material and catfish chow, and three ingredient-only diets) showed shell length growth rates of 3 mm/wk for snails fed the macroalgae *Ulva* Diet and Catfish Diet (catfish chow only) for two months. In a subsequent experiment, snails stocked at 250 snails/m^2 and fed the *Ulva* Diet grew faster than those at the same density fed the Catfish Diet. The greatest growth occurred in snails fed the *Ulva* Diet and stocked at 100 snails/m^2. Based on these results, it is recommended that the Florida apple snail be cultured in recirculating aquaculture systems with a raised substrate at 100 snails/m^2 and an artificial diet of *Ulva* macroalgae mixed with catfish chow. Snails cultured in this manner are suitable for release into the wild after three months when they reach adult size (25 mm) and reproductive maturity.

1. Introduction

In recent years, there has been interest in stock enhancement of Florida apple snail populations in areas of central and southern Florida where hydrological alteration, water management practices, and meteorological events (e.g., droughts, hurricanes) have caused declines. This interest stems from the critical role of the snail in freshwater wetland food webs. The snails are preyed upon by turtles, alligators (*Alligator missippienisis*) (Delaney and Abercombie, 1986), and bird species such as the white ibis (*Eudocimus albus*) (Kushlan, 1974), limpkin (*Aramus guarauna*), and boat-tailed grackle (*Cassidix mexicanus*) (Snyder and Snyder, 1969). Most importantly, they are the predominant food source of the federally endangered snail kite (*Rostramus sociabilis*) (Sykes et al., 1995; Snyder and Snyder, 1969). Apple snail stock enhancement could potentially reduce the recovery time of apple snail populations following extended periods of severe hydrological conditions.

Although stock enhancement is a popular method of compensating for declining aquatic species populations (Gutierrez-Gonzalez and Perez-Enriquez, 2005; Perez-Enriquez et al., 1999; Poteaux et al., 1999), there are many challenges concerning Florida apple snail production. The species has never been artificially propagated on a large scale, and its growth and survival requirements under captive conditions are not fully understood. Further, stocking expansive reintroduction areas at natural densities would require thousands to millions of snails although apple snails are found at relatively low densities (0.05 to 1 snails/m^2) in the wild (Karunaratne et al., 2006). As such, rearing space could be a key factor limiting the success of a

Abbreviations: HBOI-FAU, Harbor Branch Oceanographic Institute at Florida Atlantic University; SD, standard deviation of the mean; SL, juvenile queen conch shell length; G, weekly growth rate; W_t, shell length at time of sampling period; W_i, initial shell length; t, number of weeks; ANOVA, analysis of variance.

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large-scale stock enhancement program. Prior to this, however, a culture protocol for the Florida apple snail is needed.

Developing a program that produces growth and survival rates for cultivated animals that are equal or greater than their wild counterparts at a minimal cost is one of the most critical factors for the success of any stock enhancement aquaculture operation. It has been estimated that the growth rate of juvenile apple snails in the wild is approximately 2 to 3 mm/wk, which allows them to reach adult size (25 mm) two to three months after hatching (Darby et al., 1997; Hanning, 1979). Two variables that may influence growth and survival of the apple snail in captivity are stocking density and diet composition.

It has been suggested that the density-dependent growth of apple snails in captivity is due to metabolites or chemicals they release into the water (Carter and Ashdown, 1984; Hanning, 1979; Perry and Arthur, 1991; Thomas et al., 1975; Williamson et al., 1976). Successful apple snail culture has occurred at stocking densities of up to 20 snails/m^2 (Darby et al., 1997; Hanning, 1979), although such low densities are neither economical in an aquaculture setting nor viable for large-scale production. It may be that the small aquarium systems used in previous studies inhibited growth by magnifying chemical cues in the water, a limitation that could be mitigated or eliminated by using larger aquaculture systems that are specially designed for the needs of the snail.

Although apple snails traditionally have been cultured on a diet consisting mainly of romaine lettuce (Aufderheide et al., 2006; Conner et al., 2008; Corrao et al., 2006; Garr et al., 2008), the cost and quantity requirements of such a diet make it impractical for commercial-scale operations. Additionally, this diet may not yield the fastest growth and quickest development to sexual maturity. Several laboratory studies have shown that the Florida apple snail is capable of growth and survival while consuming a variety of resources including *Utricularia* sp. (Darby et al., 1997; Hanning, 1979; Sharfstein and Steinman, 2001), *Eleocharis* sp. (Sharfstein and Steinman, 2001), and *Hydrilla* sp. (Darby et al., 1997). Other studies have shown that artificial diets also can sustain growth and survival for many cultured species. One experimental mixture of gelatin and fish feed provided sufficient nutrients to culture *Pomacea patula* (Espinosa-Chávez and Martínex-Jerónimo, 2005), a species closely related to the Florida apple snail. Other artificial diets, such as cyanobacteria, have been used for different Pilid species (Ruiz-Ramírez et al., 2005). Artificial diets often have the additional benefits of being inexpensive and commercially available; advantages that could reduce production costs.

The objectives of this study were to determine the stocking density that supports the maximum production of healthy snails in recirculating aquaculture systems in a similar time frame as those in the wild, and to establish whether diet can improve captive growth rate at higher densities. To determine the stocking density that results in the maximum production of snails, we conducted laboratory experiments that 1) examined the effect of stocking density on growth and survival over time, and 2) determined the maximum stocking density at which growth rate begins to markedly decline. We also conducted experiments using varied diets to ascertain 3) the diet that optimizes growth and survival and 4) whether an improved diet affects growth and survival at different population densities.

2. Materials and methods

2.1. System design

All experiments were conducted in recirculating aquaculture systems constructed at Harbor Branch Oceanographic Institute at Florida Atlantic University (HBOI-FAU). The freshwater came from an underground well, and was pretreated with a degassing tower, sand filter, and biofiltration media prior to entering the aquaculture facility. Each tank had a false bottom composed of plastic grating and window screen approximately 5 cm off the bottom of the tank. The window screen was covered with 3 cm of crushed coral aragonite sand (grain size from 2 to 5.5 mm). The aragonite substrate introduced additional calcium to the system, and also served to capture solids and provide biofiltration (Davis, 2005). Water entered each tank through a PVC pipe submerged just below the surface of the water. Each system consisted of a tank with raised aragonite sand bottom, a sump, and a 1/3 to 1/2 HP pump (Fig. 1). For each experiment, plexiglass pieces were used to divide the troughs into the corresponding experimental units. The systems were located inside an aluminum greenhouse, and the daily lighting cycle was 14 h light:10 h dark. Temperature was maintained in the systems with either titanium heaters controlled by a dial thermostat, or with small submersible heaters. All tanks were drained, with the snails inside, and the substrate sprayed down with fresh water biweekly or monthly, depending on the number of snails being used in the experiment.

2.2. Experiment 1: Stocking Density Study

This experiment was conducted for eight weeks from October to December 2007 in a recirculating system consisting of two rectangular troughs (3.3 m × 0.6 m × 0.4 m), each divided into nine identical sections of 0.22 m^2 separated by plexiglass dividers. Water entered each section of the troughs through a 1/2 inch PVC pipe at an equal rate (3 l/h). Stems of vegetation with attached egg clutches were collected from Lake Kissimmee, Florida and allowed to hatch naturally in the laboratory. Newly hatched snails (3 to 4 mm) were randomly selected and stocked into each section at one of six stocking densities with three replicates per treatment: 10 snails/m^2 (2 snails per replicate), 20 snails/m^2 (4 snails per replicate), 40 snails/m^2 (9 snails per replicate), 60 snails/m^2 (13 snails per replicate), 80 snails/m^2 (18 snails per replicate), and 100 snails/m^2 (22 snails per replicate). The treatments were allocated to the location within the troughs using a randomized numbering system. The snails were fed one leaf of romaine lettuce attached to the side of the tank at the substrate level and remnants were replaced every other day. The shell length (SL) of all snails was measured at the beginning of the experiment, and at four (Month 1) and eight weeks (Month 2). Shell length, as opposed to shell weight, was monitored because it is thought to be a more important factor for reaching sexual maturity (Hanning, 1979). Shell length was determined by measuring the tip of the shell to the longest diagonal point on the lip at the aperture. Average weekly growth rates were determined using the formula:

$$G = (W_t - W_i) / t$$

where G equals weekly growth rate, W_t is the shell length of the snail at the sampling period, W_i is the initial snail shell length, and t is time in weeks. Percent survival was calculated at the end of the experiment when all remaining snails were counted. Water quality parameters were recorded throughout the experiment and the system was

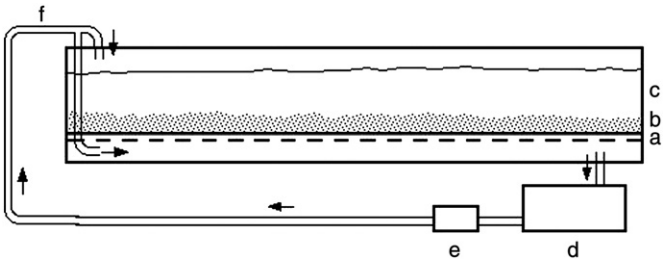

Fig. 1. Schematic diagram of an apple snail culture trough: (a) undergravel support, (b) sand substrate, (c) water column, (d) sump, (e) pump, and (f) water return. Plexiglass partitions were attached to the undergravel support. Drawing by Jackie Aronsan (Davis, 2005).