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Growth, movement and recovery of tagged topshell, *Trochus niloticus*, juveniles in Imondayon, Anda, Pangasinan, Northern Philippines

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Abstract
In the present study, the growth, movement and recovery rates of tagged wild *Trochus niloticus* juveniles were assessed after deployment in Imondayon, Anda, Pangasinan, in Northern Philippines. Two batches composed of 51 (35.88 mm shell diameter ± 3.60) and 35 (36.56 mm ± 3.73) juveniles were tagged and released into an intertidal flat with coral rubble near a sand bar in Imondayon reef on November 27, 2014 and December 18, 2014, respectively. In the first batch, only 5 live specimens were retrieved after 89 days (9.80% recovery rate). On the other hand, in the second batch a low recovery rate of 5.88% was observed after 68 days. Observed growth rates in both batches ranged from 0.052 to 0.096 mm/day, which is similar to that observed in other previous studies on same-sized juveniles. Some shells were also recovered dead but whole and with observed growth, which suggests predation by non-crushing predatory gastropods and/or hermit crabs. Wild trochus are cryptic and highly mobile, moving into deeper areas as they grow in size, which also explains the low recovery rates observed in the present study.

Keywords: *Trochus niloticus,* translocation, growth, movement, recovery

1. Introduction

Trochus niloticus Linnaeus is the most commercially important gastropod mollusk in the tropical Pacific. It is edible and valued for its nacreous shell used for the button and jewelry industries [1, 2]. They are easily harvested resulting to being overfished in many Indo-Pacific countries, including the Philippines [2]. In the Tubbataha Reefs Natural Park (TRNP), the country's largest marine protected area in Palawan, Philippines, it reaches densities of about 3,000-11,000 individuals/ha (average of 6,000/ha) as compared to densities of 0-100 individuals/ha in other open access areas in Palawan [3]. According to Dolorosa *et al.* [3], topshells have recovered from overexploitation at Tubbataha Reefs after its declaration as a national park in the early 1990s to reach several thousand individuals per hectare, but was again decimated to 1,714 individuals/ha in only two years of exploitation, and only sites close to the Ranger Station containing considerable populations [4]. Because it took about a decade or more for trochus to recover at TRNP after closure, and for the introduced trochus in countries such as French Polynesia [5] and Cook Islands [6] to reach a commercially viable population level, reviving populations in other parts of the Philippines appears to be a huge challenge.

Hatchery culture of *T. niloticus* was initially developed in Palau [2, 7] and adapted elsewhere in the Indo-Pacific. Hence, reseeding or stock enhancement of selected reefs with hatchery-cultured *T. niloticus* juveniles as a potential means of conserving this valuable island resource has long been suggested [2, 8]. Foraging habits of hatchery-reared animals paralleled those of wild specimens observed in nature, with feeding occurring primarily after dark. However, during daylight hours, most individuals remained quiescent, clumped in less lighted corner of the raceway [1].

Heslinga [1] reported that juveniles held in a flowing seawater system and fed *ad libitum* on epiphytic microalgae, filamentous green algae, and detritus reached a mean shell diameter of 6.2 cm after one year post-fertilization and attained first maturity at about 5 cm shell diameter, as verified by spawning observations.

Reseeding of cultured organisms have attendant problems, such as high rates of predation of released juveniles [9, 10]. For instance, the survival of cultured trochus <40 mm shell diameter released on coral reef flats has varied from 87% to almost total mortality after just 2 days [8, 11] whereas individuals released at a size >40 mm SD are less vulnerable to predation [10]. Dolorosa *et al.* [12, 13] suggested that the translocation of wild trochus juveniles and breeding adults could be a more effective means of reviving a depleted population in areas having no sign of recruitment.

Juvenile *T. niloticus* live among the coral rubble low on the intertidal reef flat of exposed reefs [14, 15]. Small wild juveniles (<30 mm SD) are difficult to find [11, 15, 16]. They are cryptic because of their small size, coloration being similar to those of coralline algae of the rubble on which they live and because the heterogenous substrata provide many places where juveniles can hide.

In the present study, the growth, movement and recovery rates of tagged wild *T. niloticus* juveniles (35 mm shell diameter) were assessed after deployment in Imondayon, Anda, Pangasinan to assess the potential of this technique in future stock enhancement programs.

2. Materials and Methods

2.1 Experimental Animals and Release Site

Two batches of wild topshell juveniles were collected, tagged, and released in Imondayon reef (N 16°19'23.8" E 120°01'52.7") in Anda, Pangasinan. The release site is a coral rubble area low on the intertidal reef flat behind the sand bar of Imondayon reef. The first batch comprised of 51 tagged juveniles measuring 35.88 mm ± 3.60 in shell diameter whereas the second batch was composed of 35 juveniles measuring 36.56 mm ± 3.73 in shell diameter. The first and second batch of topshell juveniles were differentiated using orange and blue Dymo numbered tags, respectively. The first batch was released on November 27, 2014 whereas the second batch was released on December 18, 2014.

2.2 Sampling for Growth, Movement and Recovery Rates

Surveys were conducted after 21, 61 and 89 days after deployment in the first batch and after 40 and 68 days after deployment in the second batch for growth measurements, observing movement, and recording recovery rates. Tagged *T. niloticus* found within 50 m radius from the release site were collected and measured for their maximum basal diameter using a plastic Vernier caliper. After measuring, the animals were immediately returned to their habitat in an upright position.

Growth rates were estimated using the formula:

Daily growth rate (mm/d) = G_{SL}/n

Where G_{SL} is increase in shell diameter or length (mm) calculated as final minus initial length, and n is number of days.

3. Results

3.1 Growth, Movement and Recovery

3.1.1 First Batch

On 27 November 2014, a total of 51 tagged wild *T. niloticus* juveniles (35.88 mm shell diameter ± 3.60) were released in Imondayon, Anda, Pangasinan.

After 21 days (18 December 2014), only 4 *T. niloticus* juveniles were recovered (7.84% recovery rate), with all 4 having travelled 30-40 m from the release site. The juveniles grew an average of 1.10 mm ± 0.45 for a daily growth rate of 0.052 mm/day.

After 61 days (27 January 2015), no orange-tagged *T. niloticus* juveniles were found for a 0% recovery rate. The site was inundated by sand because of strong waves in the area characteristic of the northeast monsoon period.

After 89 days (24 February 2015), 5 live specimens from the first batch were retrieved (9.80% recovery rate). They grew an average of 7.28 mm ± 1.45 since the experiment began, for a daily growth rate of 0.082 mm/day. One individual was found dead. It had grown 0.9 mm. Based on an estimated growth rate of 0.052-0.082 mm/day, it could have died 11-17 days post-release. The cause of death was probably not due to stress from restocking but for unknown reasons such as predation by a non-crushing predator.

3.1.2 Second Batch

On December 18, 2014, a second batch of 34 juveniles (36.56 mm shell diameter ± 3.73) were tagged and released in Imondayon, about 60 m away from the first batch.

After 40 days (27 January 2015), only 9 juveniles from the second batch were retrieved for a 26.47% recovery rate. They grew an average of 3.29 mm ± 0.84, for a daily growth rate of 0.082 mm/day.

After 68 days (24 February 2015), only 2 were retrieved alive (5.88% recovery rate). They grew an average of 6.5 mm ± 0.42 since the start of the experiment for a growth rate of 0.096 mm/day. One dead shell was observed. The dead individual had grown 5.6 mm. Based on an estimated growth rate of 0.082-0.096 mm/day of cohorts, it could have died recently at approximately 59-68 days post-release.

4. Discussion

4.1 Growth rates

Table 1 shows the growth rates of same-sized juvenile *T. niloticus* in studies done by other authors. Generally, the observed growth rates in the present study are similar to that reported in previous studies on same-sized juveniles.

Table 1: Summary of comparative growth rates of same-sized *T. niloticus* juveniles in other studies.

Growth Rates (mm/d)	Description	References
0.05-0.09 mm/d	Tagged wild juveniles 35 mm SL	Present study
0.07-<0.10 mm/d	Wild trochus of similar size	[9, 16]
0.07 mm/d	Mark and recapture	[15]
0.06 to 0.07 mm/d	Released trochus in Solomon Islands	[10]
0.07-0.13 mm/d	Hatchery-reared trochus in cages	[10]
0.087 mm/d	Small trochus in reef-based cages	[18]
0.077-0.087 mm/d	Wild trochus based on modal size progression	[9]
0.17mm/d	Small translocated trochus in Palawan	[12]
0.15 mm/d	Hatchery-reared trochus in cages	[17]
0.10-0.12 mm/d	Cultured in sea cages at 25-30/cage	[10]

Top shells placed in sea cages (10 trochus/cage or roughly 25-30 trochus/m^2) used for farming giant clam had a mean growth rate of 3.08 to 3.63 mm/month [10]. This is equivalent to 0.103 to 0.121 mm/day, which is faster than the growth rates (0.05-0.09 mm/day) observed in the present study for trochus of similar size. On the other hand, 2.1 to <3 mm/month (0.07-<0.10 mm/day) was reported for wild trochus of the same size [9, 16], which is similar to the present study. In Guam, growth rates of 25 mm in diameter per year (2.08 mm/month or 0.07 mm/day) based on mark and recapture experiments were reported, where *T. niloticus* was an introduced species [15]. With these data, it was predicted that *T. niloticus* in Guam, would take 15 years for it to reach a basal diameter of 142 mm, which is close to the theoretical maximum diameter of 146.5 mm [15]. Meanwhile, the growth of released trochus in Nusa Nane reef in the western province of Solomon Islands for 4 weeks ranged from 1.80-1.90 mm [10]. This would equate to a growth rate of 0.06 to 0.07 mm/day, also similar to the present study.

Faster growth rates among small translocated juveniles (<50 mm diameter) averaging 5 mm/month or 0.17mm/d than larger trochus (90-100 mm) ranging between 0-3.2 mm/month (0-0.11 mm/d) was observed in one site in Palawan, Philippines [12].

On the other hand, for smaller (16-25 mm diameter) hatchery-reared trochus grown in cages, growth rates of 2.1-3.9 mm/month or 0.07-0.13 mm/day were reported [10]. Meanwhile, Dolorosa *et al.* [17] stocked hatchery-reared *T. niloticus* (10–28-mm shell diameter) and reported an average growth rate of 4.4 mm/month (0.15 mm/d) for all stocking densities tested using small cages with coconut leaves as substrates and deployed at 5–6 m on the reef slope. Amos and Purcell [18] reported mean growth rate of 2.6 mm/month (0.087 mm/d) of *T. niloticus* in reef-based cages over 9 months from 15-30 mm to a sub-adult size of 40-50 mm (stocking density of 22.2 shells/m^2) for restocking. Faster growth rates were observed in the first six months (3.4 mm/month or 0.11 mm/day) but decreased thereafter in the last 3 months [18]. In another study, Castell-Perez [9] noted growth rates of (2-50 mm) trochus based on progression of modal size classes ranging from 0.077-0.087 mm/d (2.3-2.6 mm/month), also similar to the present study.

The growth rate of cultured aquatic organisms is highly variable because it is dependent on a variety of interacting environmental factors such as water temperatures, levels of dissolved oxygen and ammonia, as well as food quality and availability, and density of stocked animals. Generally, smaller and younger individuals have higher growth rates than larger and older juveniles of fish and marine invertebrates [12, 19, 20]. Clarke *et al.* [10] observed that filamentous algae and short turfing algae served as food of the trochus in their cages and in their release site.

4.2 Movement and Recovery

High survivorship of trochus reared in sea cages used for farming giant clams and afterwards releasing them into the reef flat was reported [10]. About 107 trochus (76%) were retrieved alive, 21 (15%) were dead and 12 (8.6%) unaccounted. Half of the dead shells were intact presumably being killed by whelks and hermit crabs, *Dardanus lagopodes*. In all cases of the observed predation by whelks and hermit crabs, the predator attacked the trochus through the aperture of the shell. Some dead shells were even occupied by these hermit crabs. The other half (11 of the dead trochus or 52%) were seen as broken shell fragments. Castell *et al.* [11] reported predators such as stomatopods and fish. The high recovery rates was due to the fact that researchers in that study repositioned their trochus back to the release site regularly for 4 weeks in order to relocate the trochus more easily and reduce the risk of attributing unlocated trochus “mortalities.”

Low recovery rates of trochus were observed in the present study (5.88%) after 68 days in the second batch and 9.80% after 89 days in the first batch as compared to findings of Smith at 23% in Guam [15] and at 76% in Solomon Islands after 4 weeks [10]. It was possible that we were not able to recover and retrieve some of the trochus as they were capable of moving over large distances. As an example, in the first batch, we were not able to retrieve trochus after 61 days, but five specimens were retrieved after 89 days, which could have returned within the vicinity of the release site. Mean daily movements for trochus was 1.77 ± 0.05 m SE per day, with the released trochus moving from the reef flat towards the reef crest [10]. However, Clarke *et al.* [10] also reported the range of daily movements of trochus could be 0 to 24 m per individual, although some trochus remained near a rock or patch of rubble for several days. Castell *et al.* [11], on the other hand, reported limited movement of trochus in Orpheus Island, Australia. They observed that upon deployment of the juveniles, none moved more than 1 m after 2-3 days, and only 3% moving 2 m after 10 days.

As trochus size increases, there is a change from tending to occupy small rubble to occupying rock and coral bench, and from shallow to deeper pools [9] or downward migration towards the deeper parts of the reef as individuals grew [12, 14]. Juvenile trochus live on the intertidal reef flat, which consists of abundant coralline rubble and coral bench (massive flat coral rock), with sand and colonies of live coral patchily distributed whereas adult trochus live subtidally.

The abundance of hermit crabs in a release area can be expected to be a critical factor in the survival of cultured trochus [10] and further information is needed on how, where and when to release trochus to reduce this source of predation. Castell-Perez [9] observed in laboratory studies that portunid crabs and a predatory gastropod *Thais tuberosa* prey on small trochus. *Thais*, a carnivorous muricid gastropod, attacks prey through the aperture, leaving the shell clean and undamaged. Shallower areas with small rubble may be safer for small trochus if they offer risk to potential predators, such as low availability of refuges to escape from other low tide predators (i.e. eels and birds), or high risk of getting stranded as the tide goes out.

Juvenile *T. niloticus* are very cryptic because of their small size and the complexity of the reef surface where they live [15]. Castell *et al.* [11] compared recapture rates of cultured trochus after 2-3 days in two areas (Orpheus Island, Australia and Moso Island, Vanuatu) with only a numbered tag with that of flagged trochus (having both a tag and an additional bright colored tape glued to shell) and concluded a higher recapture of flagged trochus. This implies that a significant proportion of the trochus are overlooked by the observer. This observation of Castell *et al.* [11] also partially explains the “unaccounted for” trochus in this study. The unaccounted specimens may be due to the fact that some trochus are eaten and their shells not recovered, some may disperse, and some could be missed by the observer during the census [11, 15].

Without appropriate correction, survival rates could be underestimated by as much as 30% in an area (Orpheus Island) using small juveniles [11] Sighting probability varies with locality and size of juveniles used. Hence, it is recommended that the estimation of sighting probability of juvenile *T. niloticus* be conducted as an essential component of reseeding experiments in different areas as recommended by Castell *et al.* [11].

In a survey of *T. niloticus* in Guam, where it was introduced, greater numbers were found on the leeward side than on the windward side and that smaller size classes occupied the outer reef flat and reef margin zones whereas larger animals inhabited deeper water on the submarine terraces [15]. This implies that the reef flat serve as nurseries for *T. niloticus* and the subsequent migration of larger sized individuals as they increase in size and age.

Dolorosa *et al.* [12] suggested that translocation of wild trochus into sites at which they were previously been found are likely to be suitable for their growth and survival, wherein they observed high survival probabilities ranging between 0.77 and 0.92. If site management can control over-fishing, this approach is likely to be a valuable tool for enhancing field populations of a large invertebrates like *Trochus* in Anda, Pangasinan, that have a short-lived planktonic larva, and should be used in conjunction with other resource management options, such as marine protected areas, minimum size limits, strong information education campaigns, etc.

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