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*Vachellia nilotica*

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**Cover: Parts of *Vachellia nilotica*, medium - watercolours. © P Kritika**

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ARTICLE

# Abundance, habitat preference, and ethnobiological assessment of the invasive Golden Apple Snail *Pomacea canaliculata* (Lamarck, 1822) in selected rice fields in Lanao del Sur, Philippines

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**Abstract:** This study assessed the abundance, habitat preference, and ethnobiological impacts of the Golden Apple Snail (GAS) *Pomacea canaliculata* in selected rice fields in Lanao del Sur, Philippines. Employing the Lincoln-Petersen estimator, the population was estimated at 184 individuals during the initial sampling and increased to approximately 920 in the subsequent period, reflecting a significant rise over time. The combined density of adults and juveniles ranged 0.75–0.96 individuals per $m^2$ in the first period, and 2.00–3.39 individuals per $m^2$ in the second. Adult snails were mostly associated with water and sediment, while juveniles concentrated primarily in sediment. Egg clutch density was higher in the first sampling period (0.30 clutches) compared to the second (0.12 clutches), with leaf sheaths identified as the preferred oviposition site. Water temperature ranged 22.7–27.0 °C, pH 6.83–7.23, relative humidity 83.5–89.2 %, and water depth 4.5–13 cm, indicating that warmer, deeper, and more humid conditions promoted increased activity and abundance. Ethnobiological data revealed that farmers regard GAS as a serious pest that reduces rice yields, threatens livelihoods, and poses health risks, including injuries, pesticide irritation, and schistosomiasis. While traditional methods and synthetic pesticides are used, farmers find these approaches costly, labor-intensive, and only partially effective. Overall, findings highlight that *P. canaliculata* is an abundant, adaptable invasive species threatening rice agriculture, livelihoods, and public health. This underscores the urgent need for integrated, sustainable, and community-based management strategies.

**Keywords:** Cultural intersection, density, farmer perceptions, integrated pest management, invasive alien species, Lincoln–Petersen estimator, mark–recapture, microhabitat, oviposition, physicochemical factors.

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## INTRODUCTION

The Golden Apple Snail (GAS), *Pomacea canaliculata* (Lamarck, 1822), belonging to the family Ampullariidae, is commonly referred to as 'golden kuhol' in the Philippines. This sizable freshwater snail is indigenous to the tropical and subtropical regions of South America (Halwart 1994; Cowie et al. 2006; Hayes et al. 2008). During the 1980s, it was introduced to other regions and subsequently proliferated extensively in Asia for commercial purposes aimed at augmenting human diets and animal feed, owing to its high nutritional value, while simultaneously generating income for both rural communities and affluent nations (Naylor 1996; Cowie et al. 2006; Casal et al. 2017; Heuzé & Tran 2017). Thereafter, domestication efforts expanded to the aquarium trade, biological control of parasitic snail vectors responsible for schistosomiasis, control of aquatic weeds, and utilization as a liquid biofertilizer (Ranamukhaarachchi & Wickramasinghe 2006; Cowie et al. 2017). The presence of GAS in the Philippines was documented between 1982 and 1984, after which it emerged as a notorious agricultural pest in rice cultivation systems (Joshi et al. 2001).

The dispersal of this invasive species has occurred through extensive irrigation networks, subsequently spreading into rice fields, where it feeds on seedlings. The proliferation of GAS posed a substantial threat to rice production and food security in the Philippines, rendering this species a major concern for irrigated rice farmers (Joshi et al. 2001; Adalla & Magsino 2006). Initial reports indicated that the area of GAS infestation in the Philippines ranged from approximately 400,000 ha to more than 800,000 ha, while Filipino farmers incurred substantial expenditures amounting to at least USD 1 billion in efforts to control and eradicate this rice pest (Cagauana & Joshi 2002; Adalla & Magsino 2006). Subsequently, it was classified among the top 100 most invasive alien species worldwide (Joshi 2005b). The extent of infestation continues to escalate, expanding beyond national borders into neighboring southeastern Asian countries and regions farther afield (Joshi 2005a; Ranamukhaarachchi & Wickramasinghe 2006; Hayes et al. 2008; Cowie et al. 2017). Beyond its impact on rice crops, GAS also feeds on and damages adjacent paddy crops such as lotus, taro, and *Ipomoea aquatica* (Ranamukhaarachchi & Wickramasinghe 2006). Moreover, reports indicate that the invasion of such snails has disrupted the ecological functions of wetlands in southeastern Asia, Europe, and North America, reducing native aquatic vegetation and inducing significant habitat alterations, including the dominance of planktonic algae and increased water turbidity (Carlsson et al. 2004; Carlsson 2017).

Hayes et al. (2015) provide a comprehensive review of prior accounts, including phylogenetic and biogeographic studies of *P. canaliculata*. In its native habitat, this organism reproduces only in summer or autumn, whereas in southeastern Asia it reproduces three to four times annually due to the year-round warm climate (Cowie 2002; Hayes et al. 2008). The warm season provides favorable conditions for accelerated growth, thereby shortening the interval between a female's initial oviposition (Estebenet & Martin 2002). The increased growth rate of GAS may offer valuable insights into estimating its abundance. This organism inhabits ecologically diverse habitats and exhibits complex, morphologically divergent populations. This species is prevalent in both natural and managed systems within the Philippines. Morphological differences observed across developmental stages can correlate significantly with habitat type, thereby reflecting density variations in this species (Torres et al. 2011). The organism's behavior suggests that environmental factors may influence the quantity of GAS.

The investigation of species density provides insights into the frequency of animal occurrence within a specified environment. Such analysis contributes to a comprehensive understanding of an area's overall biodiversity. Existing studies clearly establish GAS as a serious agricultural and environmental threat in the Philippines (Joshi et al. 2001; Cagauana & Joshi 2003; Adalla & Magsino 2006; Penaredondo et al. 2015). However, they are largely generalized at regional or national scales and seldom integrate ecological measurements with ethnobiological knowledge at the community level. As a result, the specific patterns of abundance, habitat preferences, and environmental correlates of GAS populations in Barangay Dangiprampiai Proper, Ditsaan-Ramain, Lanao del Sur, and how these intersect with local farmers' management practices, remain undocumented. This gap limits the development of context-appropriate, culturally grounded control strategies for this high-risk area, which is heavily dependent on rice cultivation.

## MATERIALS AND METHODS

### Study site

This study was conducted in Barangay Dangiprampiai Proper, Ditsaan-Ramain, Lanao del Sur (Image 1). The population was predominantly Meranao, an ethnic group local to the region.

**Study research design and ethical considerations**

The study employed an observation approach that involved measuring ecological units under natural conditions without experimental manipulation (Hurlbert 1984). This design was chosen because the primary objectives were to estimate the density and structure of GAS populations under typical rice-field management practices and to document farmers' knowledge and perceptions. Manipulating water levels, pesticide use, or farmer practices was not feasible or desirable due to ethical and logistical constraints and the need to maintain the integrity of farmers' fields. The mensurative design emphasizes careful measurement of a specific set of factors of interest (e.g., snail density, developmental stages, habitat characteristics, and farmers' perceptions), while recognizing that not all environmental and management variables influencing the data can be controlled. Unlike manipulative experiments, observational studies involve sampling across different times or locations to capture natural variation (Hurlbert 1984).

Prior to conducting the study, ethical clearance was obtained from the research ethics committee (REC) of Mindanao State University – Marawi (MSU REC Code: 2023-002). Informed consent was secured from both the barangay authorities and the rice field owners at the sampling site. A gratuitous permit (No. 33-BARMM-2022) was also secured from the Ministry of Environment, Natural Resources and Energy (MENRE) of the Bangsamoro Autonomous Region in Muslim Mindanao.

**DATA GATHERING PROCEDURE**

**A. Sampling method**

The researchers employed the quadrat mark-recapture method during two sampling periods (Image 2). Each period consisted of two phases: the initial capturing (capture phase) and the second capturing (recapture phase). This study primarily adopted a closed-population mark-recapture approach to estimate the population size of mobile organisms, following the methods of Fontoura-da-Silva et al. (2013) and Lettink & Armstrong (2003), which were considered reliable for estimating abundance

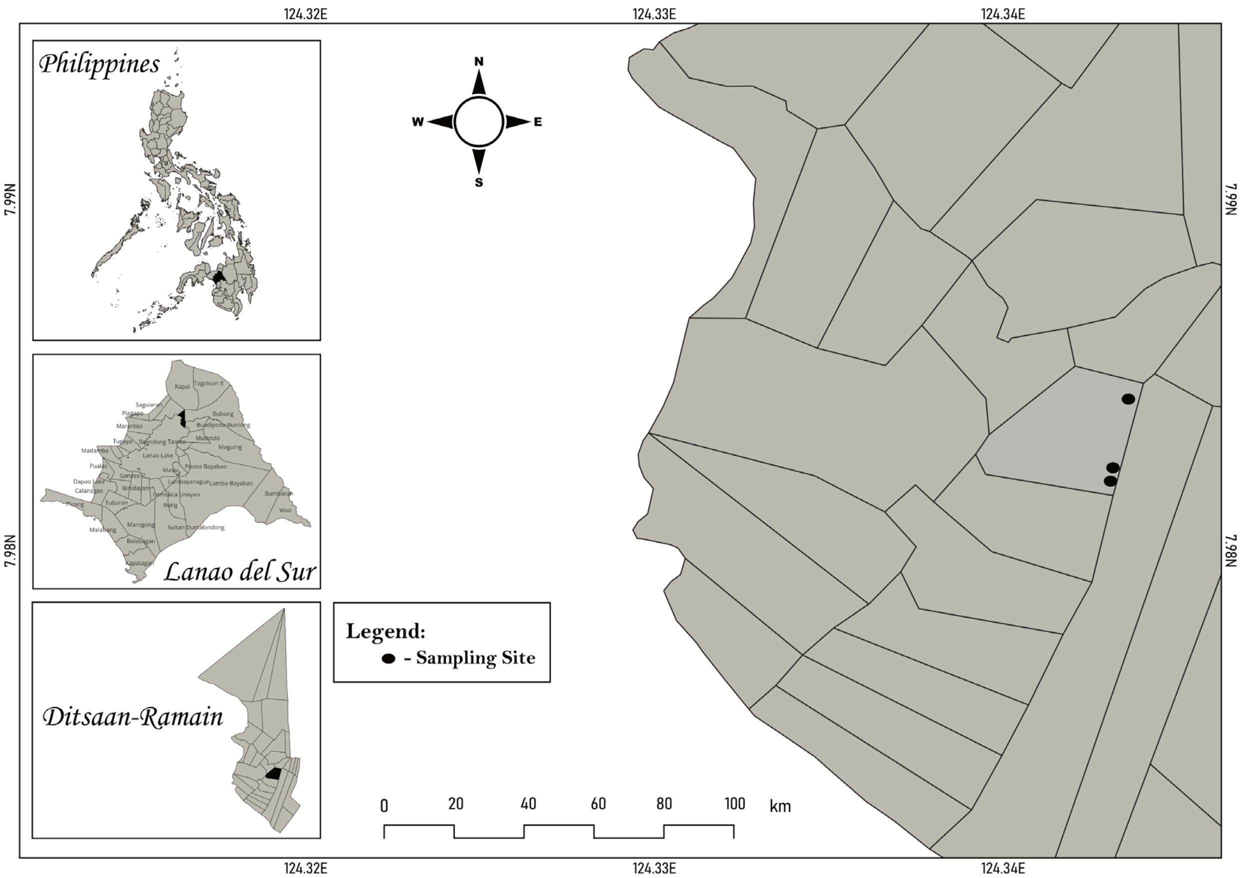


Image 1. Map of the study area showing sampling sites.


**Image 2. Established sampling quadrats (A–C) with 46-day-old rice seedlings.© Ashiah M. Dimalutang.**

in small, spatially defined areas (Krebs 2014). The quadrat mark-recapture was selected because the relatively slow-moving, easily observable snails in flooded rice fields allow estimation of absolute density and population size with modest field resources, and quadrats provide a standardized sampling unit for comparing snail densities among stations and between sampling periods. A closed-population assumption over the short sampling interval (e.g., 2–3 days) was considered reasonable because major recruitment or mortality were unlikely within this timeframe under typical field conditions.

In the quadrat mark-recapture method, three sampling stations measuring 4 x 4 m (16 m$^2$) each were established, resulting in a total of 48 quadrats. These quadrats were delineated using plastic rope and bamboo pegs. The number of quadrats and station size were determined to balance logistical constraints with the need to obtain sufficient spatial coverage and sample size to estimate density with acceptable precision. Trapped and encountered GAS within the sampling stations were counted and collected. During the initial capture phase, snails were manually picked up and marked with yellow nail polish on their shells. The marks were allowed to dry thoroughly before the snails were released back into the trapped area where they were originally found (Valentine-Darby et al. 2008; Fontoura-da-Silva et al. 2013). Manual collection was used because it is a standard, low-impact method suitable for shallow, vegetated rice paddies where more complex trapping devices are impractical.

The developmental stages and habitat preferences of the snails were also recorded. The developmental stage of each snail was determined based on shell diameter (Estebenet & Martin 2002), while egg clutch density was assessed by counting egg clusters per unit area (Teo 2004). Egg clusters were evaluated as a potential index of snail abundance due to their conspicuousness and ease of counting. Additionally, the microhabitat of individual snails and egg clutches was documented, and the water level in the rice field was measured. Morphological characterization of the shells followed the criteria outlined by Cowie (2002) and PhilRice (2001). After the first sampling period, the collected snails were identified and verified.

The recapture phase occurred two days after the initial sampling during both sampling periods. This interval was chosen to allow snails sufficient time to resume natural behavior and redistribute within quadrats, while minimizing violations of the closed-population assumption due to recruitment, mortality, or movement in and out of the study area. The recapture phase employed the same methods as the initial phase; however, the snails collected during the recapture phase were not released back into the field. Adult snail shells were retained for detailed morphological analysis. To prepare the collected snails, they were boiled for 30 minutes to remove the flesh, then soaked in soapy water with alum (tawas) powder for three nights to eliminate odor. Afterward, shells were measured for length and diameter to aid in developmental stage classification and sex determination. Sex ratio was determined for each sampling period to explore its relationship with egg clutch density. Sex determination was based solely on shell morphology (Philrice 2001; Teo 2004).

Physico-chemical parameters (water temperature, pH, and relative humidity) were measured during each sampling phase using a field thermometer, a pH meter, and a psychrometer. Prevailing weather conditions were also recorded to provide context for interpreting snail activity and detectability.

**B. Ethnobiological survey**

The ethnobiological component was designed to complement the ecological data by documenting local knowledge, perceptions, and management practices related to GAS. The eligibility criteria identified male Filipino Meranao farmers with substantial field experience, as they are typically the primary decision-makers for rice cultivation in the area. Participants were certified rice farmers over 30 years old with more than 5 years of field experience in rice cultivation. Respondents were identified and selected through referrals from the barangay chairman and other credible individuals to ensure the authenticity of the information collected. This purposive and referral-based sampling strategy was chosen to target key informants who could provide in-depth, experienced-based insights. A semi-structured questionnaire was prepared following Penaredondo et al. (2015) and Schneiker et al. (2016), and then translated and transcribed as needed to ensure clarity and cultural appropriateness. During the focus group discussions (FGDs), five groups, each consisting of five to seven members, were organized to elicit more detailed and nuanced information, encourage interaction among participants, and validate emerging themes through group discussion.

**Data analysis**

**Density estimation**

The mark-recapture method served as the primary basis for estimating the population size at the time of marking and release. Snails captured during the first phase of both sampling periods were marked and released back into their original habitat. After three days, a second set of samples was taken. The number of marked snails that were recaptured in the second sample I, the total number of snails captured in the second sample I, and the total number of marked individuals originally released (M) were recorded to estimate the population size (N). Lincoln-Petersen method was used to determine absolute abundance (Krebs 2014). The following formula was used to compute for (N):

$$R/C = M/N \quad \text{-------->} \quad N = CM/R$$

The physico-chemical parameter analysis was computed as an average across three trials. Meanwhile, ethnobiological assessments were organized and categorically coded into themes.

The study's analytical approach focused on density estimation via the Lincoln-Petersen method and descriptive statistics for several reasons. Its main goal was to establish baseline data on GAS density, stages, sex ratio, environmental factors, and farmers' practices, emphasizing estimation and description over hypothesis testing or complex models. More advanced methods were avoided due to limited sampling stations and quadrats, which constrained spatial and temporal data and risked bias. Sampling relied partly on farmers' willingness to allow repeated access, further limiting opportunities. Ethnobiological data were mainly qualitative and categorical, making thematic analysis more suitable than sophisticated statistical techniques. Thus, simple density estimates and descriptive stats were the most appropriate tools for addressing the questions without overstating precision or scope.

## RESULTS

**Abundance of GAS**

The abundance of GAS across the three established sampling stations was assessed during two sampling periods, corresponding to rice plants aged 46 and 75 days, respectively. In the first sampling period, a total of 36 snails were collected during the capture phase and 46 during the recapture phase, with only 9 adult snails marked with yellow nail polish recovered, and none of the juveniles were recaptured. In the second sampling period, 163 snails were collected during the capture phase and 96 during the recapture phase, with 17 marked snails recaptured.

Based on the Lincoln-Petersen method, the estimated population size was 184 during the first sampling period and 920.47 in the second. This indicates that snail abundance (including both adults and juveniles) was greater in the latter sampling period. The average snail densities for each period are presented in Image 3.

During the first sampling period, adult snails had an average density ranging from 0.56 to 0.90 per m$^2$, juveniles from 0.06 to 0.19 per m$^2$, and egg clutches from 0.27 to 0.33 per m$^2$. In the second sampling period, adult snail density ranged from 1.06 to 1.10 per $m^2$, juveniles from 0.90 to 2.33 per $m^2$, and egg clutches from 0.10 to 0.13 per $m^2$. The combined average density of adults and juveniles ranged from 0.75 to 0.96 per $m^2$ in the first sampling period and from 3.39 to 2 per $m^2$ in the second. Furthermore, egg clutches were more abundant in the first sampling period, with an average of 0.30 clutches compared to 0.12 in the second period.

**Morphological sex ratio of GAS**

A total of 92 adult snails were recaptured, 43 during the first sampling period and 53 during the second. In the latter sampling, four snails were discarded from the analysis due to disintegrated spires, which rendered them unsuitable for further examination. Of the remaining 92 snails, 38 were identified as adult males and 54 as adult females.

Based on morphological characterization, including both internal and external sexual dimorphism, the male-to-female sex ratio was 1:1.53 in the first sampling period and 1:1.33 in the second. These differences in sex ratio highlight the greater abundance of egg clutches observed in the first sampling period, which recorded 16 clutches at a density of approximately 0.30 clutches. In contrast, the second sampling period yielded only six egg clutches, with a density of 0.12 clutches.

**Habitat preference**

GAS habitat preferences varied across stages and sampling periods, showing that microhabitat use depends on development and field conditions. Snails were found in various microhabitats during both capture and recapture, including leaf surfaces, leaf sheaths, water, and sediment (Images 4 & 5). Sediment was muddy soil, and water was the supernatant layer where snails crawled in paddies. These findings indicate that GAS does not occupy the paddy evenly but instead partitions microhabitats based on behavior, development, and physicochemical conditions.

Adult snails were mainly concentrated in water and sediment across both sampling periods, with some on mature leaves and leaf sheaths where rasping and egg laying occurred. Water and sediment serve as the primary zones for survival, movement, and reproduction, while plant structures serve as temporary feeding and egg-laying sites. The increased adult numbers in water and sediment during the second sampling, including on half-submerged leaf sheaths, may indicate habitat shifts due to better mobility in wetter conditions or higher reproductive activity, with shallow standing water boosting encounter rates, copulation, and reproduction.

In contrast, juvenile snails were predominantly found in the sediment, revealing a clear difference in habitat preference. At this stage, juveniles appear to be more constrained than adults in their ability to use elevated plant surfaces. Their concentration in muddy sediment suggests that this microhabitat provides both physical refuge and immediate access to soft plant tissues, such as leaves and leaf sheaths or to decaying organic matter at the base of rice seedlings. Although their tissues are already developed, their limited climbing capacity and underdeveloped rasping mechanisms likely restrict their use of emergent rice stalks. This explains why juveniles were chiefly found feeding on tissues of leaves and leaf sheaths of young rice seedlings near or within the sediment interface. During the second sampling

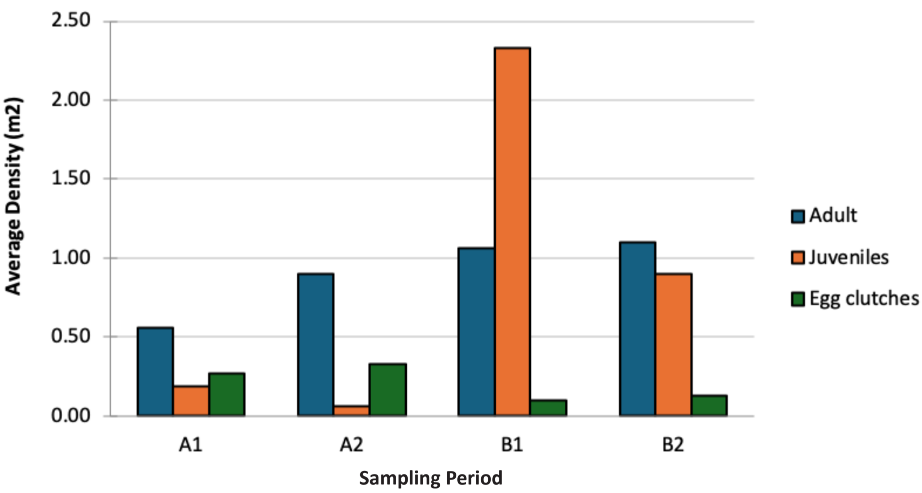


**Image 3. Average density of different Pomacean snail stages across both sampling periods. A1–A2 Correspond to the first sampling capture and recapture phases and B1–B2 Correspond to the second sampling capture and recapture phases.**

**Table 1. Average physico-chemical parameters recorded during the sampling periods.**

| Physico-chemical parameters | Capture phase | | Recapture phase | |
|---|---|---|---|---|
| | First | Second | First | Second |
| Temperature ($^oC$) | | | | |
| air | 20.87 | 19.30 | 19.30 | 18.50 |
| water | 26.98 | 24.19 | 24.59 | 22.69 |
| soil | 19.45 | 20.72 | 19.00 | 20.06 |
| pH | | | | |
| water | 6.83 | 7.23 | 6.83 | 6.85 |
| soil | 6.58 | 6.65 | 6.47 | 6.54 |
| Relative humidity (%) | 83.47 | 88.00 | 85.55 | 89.17 |
| Depth (cm) | 4.5 | 12 | 6.5 | 13 |

**Table 2. Respondent's profile.**

| Coded respondents | Age | Gender | Civil status | Years of farming |
|---|---|---|---|---|
| A01 | 43 | Male | Married | 30 |
| A02 | 45 | Male | Married | 10 |
| A03 | 35 | Male | Married | 10 |
| A04 | 36 | Male | Married | 5 |
| A05 | 35 | Male | Married | 7 |
| A06 | 41 | Male | Married | 9 |
| B07 | 30 | Male | Married | 20 |
| B08 | 55 | Male | Married | 43 |
| B09 | 32 | Male | Married | 10 |
| B10 | 57 | Male | Married | 37 |
| B11 | 60 | Male | Married | 32 |
| B12 | 59 | Male | Married | 35 |
| B13 | 42 | Male | Married | 23 |
| C14 | 32 | Male | Married | 12 |
| C15 | 30 | Male | Married | 5.5 |
| C16 | 38 | Male | Married | 10 |
| C17 | 39 | Male | Married | 10 |
| C18 | 30 | Male | Married | 6 |
| C19 | 40 | Male | Married | 20 |
| D20 | 42 | Male | Married | 15 |
| D21 | 40 | Male | Married | 17 |
| D22 | 30 | Male | Married | 10 |
| D23 | 37 | Male | Married | 10.5 |
| D24 | 38 | Male | Married | 12 |
| E25 | 43 | Male | Married | 20 |
| E26 | 30 | Male | Married | 11 |
| E27 | 31 | Male | Married | 10 |
| E28 | 42 | Male | Married | 14 |
| E29 | 39 | Male | Married | 10 |
| E30 | 38 | Male | Married | 13 |

period, a higher and more active number of juveniles was recorded in the sediment, with some also found on half-submerged leaf sheaths or floating in the water while feeding. Relative to the first sampling period, this broader microhabitat distribution may reflect either increased activity under favorable water conditions or a slight ontogenetic transition toward more active foraging as juveniles developed. The increased juvenile activity during the second sampling may also be linked to wetter field conditions. Such conditions may reduce the risk of desiccation and soften the sediment, making movement and feeding easier for smaller individuals. Notably, juveniles were absent from water and leaf blades during the first sampling, underscoring that their habitat breadth was narrower earlier in the observation period. An important result from both sampling periods is the apparent avoidance of leaf blades by both adults and juveniles. Neither developmental stage was recorded on leaf blades despite their availability in the paddy. This consistent absence suggests that leaf blades may be less suitable than leaf sheaths or basal tissues, possibly because of their surface texture, exposure, lower structural stability, or reduced accessibility relative to the snail's locomotor and feeding behavior. Since the leaf sheaths are closer to the waterline and provide firmer attachment surfaces, they may offer a more favorable interface for both feeding and resting than the more exposed leaf blade.

The temporal differences between the first and second sampling further indicate that GAS microhabitat use is dynamic rather than fixed. The second sampling showed a greater concentration of both adults and juveniles in water and sediment. This shift may signify changes in water depth, sediment softness, plant architecture, or population activity over time. Such temporal plasticity is ecologically important because it suggests that GAS can rapidly adjust its spatial distribution within rice paddies in response to changing environmental conditions. This flexibility may help explain the persistence of GAS in rice-based systems, as different microhabitats can simultaneously support different life stages.

In addition to the distribution of active snails, the oviposition data provide further evidence of selective habitat use. Egg laying was predominantly observed on hard soil substrates, such as levees, and on emergent plants, such as *Ipomoea aquatica* (locally known as kangkong), in adjacent paddy fields. Egg clutches were also observed on the leaf sheaths of rice crops in both sampling periods. Among the four identified oviposition habitats, leaf sheaths were the most preferred. This

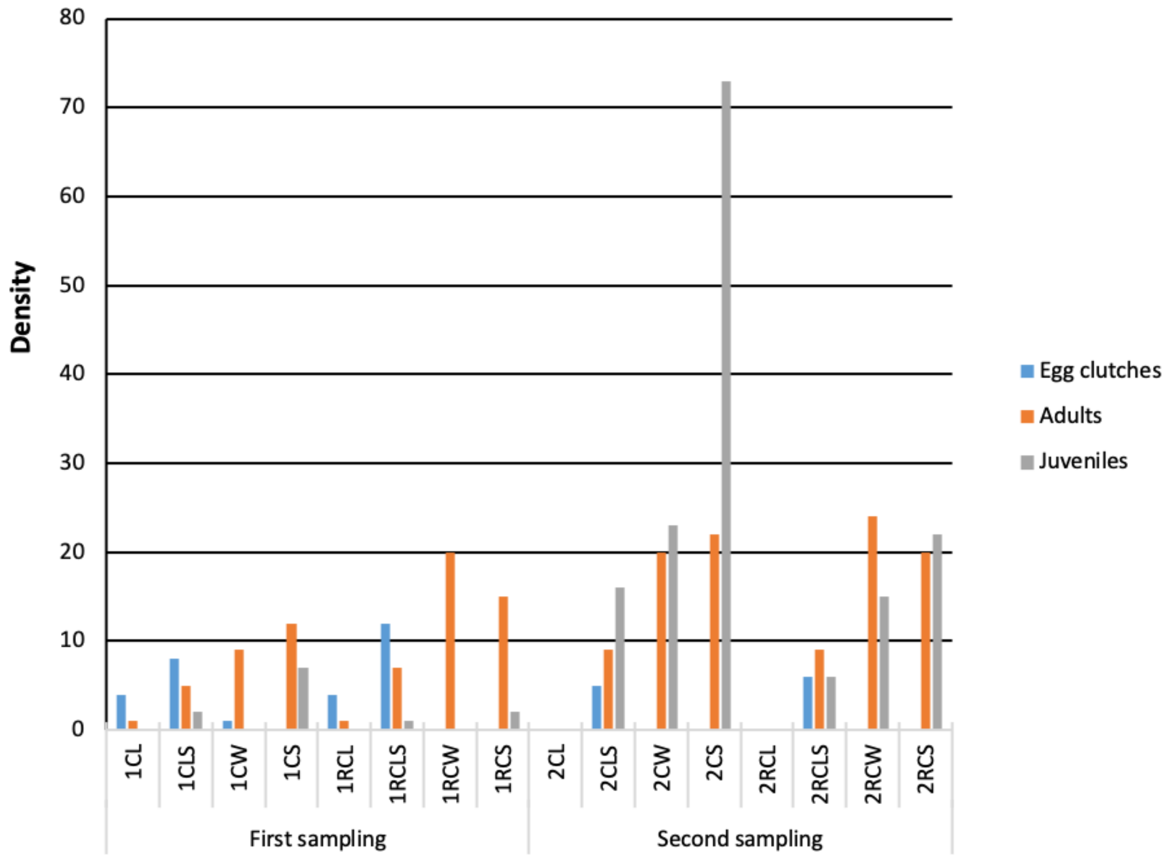


**Image 4. Developmental stage density count of snails in their microhabitat: 1—First sampling | CL—Capture Leaf | CLS—Capture Leaf Sheath | CW—Capture Water | CS—Capture Sediment | RCL—Recapture Leaf | RCLS—Recapture Leaf Sheath | RCW—Recapture Water | RCS—Recapture Sediment | 2—Second sampling.**

pattern strongly suggests that oviposition site selection is driven by the need for stable, elevated, and relatively dry substrates that reduce the risk of clutch loss or prolonged inundation. Leaf sheaths may represent an optimal oviposition site because they are readily available within the crop stand, positioned above the water surface, and close to feeding areas used by adults. By contrast, the single egg clutch observed floating during the first sampling was likely an atypical case resulting from detachment from an unstable substrate, as no floating or submerged clutches were found in the subsequent sampling. This supports the view that successful oviposition depends on secure attachment to emergent surfaces rather than on random deposition. The use of kangkong and levees suggests that surrounding vegetation and field margins may function as important reproductive refuges. Consequently, management strategies focused only on the rice canopy may underestimate the true reproductive habitat available to GAS. The preference for leaf sheaths, levees, and emergent weeds also implies that habitat complexity within and around paddies may enhance reproductive success by increasing the number of suitable egg-laying substrates. Although eggs were associated with elevated substrates rather than submerged areas, the surrounding moisture regime remains important because humid field conditions may help prevent excessive drying of freshly laid clutches while still allowing them to remain above the waterline.

GAS distribution shows clear ecological partitioning by life stage and function. Sediment and shallow water appear to be the core habitats for movement, feeding, and mating, especially for adults, while juveniles remain more strongly tied to sediment microhabitats. Emergent structures, like leaf sheaths, serve as feeding surfaces and oviposition sites. These patterns reveal the interaction between paddy hydrology, plant structure, and GAS development. This flexible habitat use indicates this species is well adapted to the variable conditions of rice ecosystems, aiding its persistence, dispersal, and pest status in flooded fields.

**Physico-chemical factors**

The average physico-chemical results are presented in Table 1. During the capture phase of the first sampling,


**Image 5. Varying habitat preference of GAS: A & B—Juvenile and adult in sediments | C—Egg clutch in leaf/leaf sheath | D—Adult in water | E & F—Ovipositions in water spinach and levee. © Ashiah M. Dimalutang.**

the highest recorded temperature was in water at 26.98 °C, followed by air at 20.87 °C, and soil at 19.45 °C. In the second sampling, water temperature was 24.19 °C, followed by soil and air at 20.72 °C and 19.30 °C, respectively.

For the first sampling, water had a pH of 6.83, and soil had a pH of 6.58. In the second sampling, water had a slightly more alkaline pH of 7.23, while soil had a pH of 6.65. Relative humidity and water depth during the first sampling were 83.47% and 4.5 cm, respectively; these increased to 88.00% and 12 cm in the second sampling. Meanwhile, in the recapture-phase sampling, the highest temperature was again observed in water at 24.59 °C, followed by air at 19.30 °C and soil at 19.00 °C. In the second sampling, water remained the warmest at 22.69 °C, with soil and air measuring 20.06 °C and 18.50 °C, respectively. The pH of the first sampling was 6.83 for water and 6.47 for soil. In the second sampling, pH values were 6.85 for water and 6.54 for soil. Relative humidity and water depth were recorded at 85.55% and 6.5 cm during the first sampling and increased to 89.17% and 13 cm in the second sampling.

**Ethnobiological survey**

All participants were male, married, of legal age, and had sufficient experience in rice farming (Table 2).

During data analysis, three main themes emerged that enriched the understanding of GAS invasion. These themes addressed several aspects, including the origin of invasion, feeding mechanisms, the extent of damage to the rice system and farmers' livelihoods, factors contributing to the increasing snail population, control measures employed by farmers, and other related concerns like health risks. The identified themes were categorized as: 'What Do I Know', 'What Do I Do,' and 'Presence of Challenges' (Table 3).

## DISCUSSION

The Lincoln-Petersen index indicated high GAS abundance, with a density of over 0.5 individuals per m$^2$ across sampling periods, matching Basilio (1991). This may cause up to 6.5% rice field damage, with densities of 1–8 snails per m$^2$ linked to up to 93% damage and 20–90 % yield loss (Basilio 1991; Naylor 1996; Joshi 2005b; Arfan

**Table 3. Responses on the derived and corresponding sub-themes on P. canaliculata.**

| Themes | Sub-themes | Responses |
|---|---|---|
| Theme I: What Do I Know | General knowledge | Described locally as "rambuwan", pest, and can further inflict injury. |
| | Origin of its invasion | Brought in the region from neighboring provinces due to flooding or human cultivation. Some believe it developed organically, while others believe it was created by God. |
| | Feeding mechanism & extent of damage on rice crops | Causes major crop loss by feeding on stems and leaves, and is highly destructive to young rice seedlings. During the wet season, GAS becomes widespread, reproduce quickly, and is difficult to control. Its infestation seriously threatens rice yields and farmers' livelihoods. |
| | Factors influencing increasing density | Deep water is a prerequisite for reproduction. Infestation worsen during flooding, poorly designed rice fields, in inadequately irrigated, and snails' capacity to withstand dry weather and reappear after rain. |
| | Boon or Bane | *P. canaliculata* is a bane. |
| Theme II: What Do I Do | Government Initiatives | Inconsistent efforts in managing the GAS. Some recalled past seminars and the use of a substance called "ukap" to control snails, though most information focused on rodents. |
| | Traditional methods on snail management | Farmers use labor-intensive strategies such as manual removal, pesticide application, constructing of drainage ditches to regulate population, and feeding the snail to ducks. |
| | Use of modern synthetic pesticides | Rely on pesticides ('timpla', 'surekill', and 'furadan') to control, ensuring crop survival and healthy growth. Although these are considered essential, some farmers prefer manual removal of snails to avoid the unpleasant odors from chemical use, while other methods, such as lowering water levels, can lead to excessive weed growth. |
| Theme III: Presence of Challenges | Financial struggles | Many farmers face financial struggles, forcing them to reduce or discontinue the use of synthetic control methods. As a result, they merely tolerate the damage. |
| | Challenges of farming practices | Lack of a collaborative farming schedule among farmers makes rice fields more vulnerable to pests and complicates pest management. |
| | Health risks | Physical injuries from stepping on sharp shells can cause bleeding, delayed healing, and schistosomiasis. Additionally, the use of pesticides during fieldwork often led to eye irritation and vision problems. |

et al. 2017). Cowie (2002) found that an adult snail can eat about 24 young rice seedlings daily. Snails over 5 cm cause three times as much damage as those under 2 cm; those under 5 mm feed on algae and detritus. Horgan (2018) added that large snails eat older seedlings (30–40 days or more), while hatchlings and small snails feed on young seedlings and cotyledons, as seen in missing rice hills and floating plant fragments.

Egg clutch density declined during the second sampling, likely due to changes in food availability, abiotic factors, and human intervention. Mature seedlings, especially transplanted ones, develop thicker stems that resist snail damage even at high snail densities (Figueroa et al. 2014). These sturdy stems also allow female snails to climb and deposit eggs above water. Studies report that females may delay reproduction when food is limited (Estoy et al. 2002; Tamburi & Martin 2009). Consequently, egg numbers decline during the first reproductive month due to reduced food availability (Estoy et al. 2002; Tamburi & Martin 2009), resulting in fewer egg clutches later, coinciding with reduced food availability during rice maturation and pre-harvest.

Temperature strongly influences the activities of apple snails such as *P. canaliculata* (Wada & Matsukara 2007, 2011; Seuffert et al. 2010; Bae et al. 2021). Water and air temperatures of 15–20 °C decrease egg-laying, while 20–32 °C promote mating. The optimal range for both is 25–30 °C, associated with higher populations (Seuffert & Martin 2013; Bae et al. 2021). High temperatures and dry periods enable snails to grow and mature rapidly in tropical rice paddies (Cowie 2002; Teo 2004), with continuous reproduction and egg-laying (Estebenet & Martin 2002; Stuart et al. 2014). Egg clutches outside optimal temperature are low in density. Egg-laying occurs above water on plant stems or structures. The presence of clutches indicates high pest population growth, as seen during the second sampling. Egg clutch sizes vary, but damage to rice fields mainly comes from high GAS density. Snail damage in irrigated rice depends on crop age, snail size and density, water levels, and environmental factors (Basilio 1991; Horgan 2018; Gilal & Muhammad 2020).

Snails damage rice by rasping seedlings (Horgan 2018). Factors like water depth, seedling age, and snail density influence vulnerability (Litsinger & Estano 1993; Teo 2003). During this period, snails forage, mate, and reproduce (Burela & Martin 2007; Takeichi et al. 2007). When water is above snail shell height, their mobility increases, causing more damage (Sanico et al. 2002; Teo 2003; Liang et al. 2014; Gilal & Muhammad 2020). Water also provides food (young rice seedlings) (Teo 2003). Teo (2003) noted that at water depths over 5 cm, snail damage was 100%, 89.2%, 59.7%, and 46% for rice seedlings at 21, 30, 40, and 50 days old, respectively. Infestation rises during the rainy season, aiding the spread of snails and their invasion. Low snail counts may result from sampling methods and climatic conditions, which affect reproduction. GAS can hibernate by burrowing into mud, slowing metabolism until conditions improve (Rodriguez et al. 2023; Yao et al. 2024). Burrowing 5–10 cm helps snails survive low water and heat (Wada & Yoshida 2000; Zhang et al. 2023). Increased snail density in the second period likely stems from rain raising water levels, encouraging snails to re-emerge and spread (Joshi 2005a; Liang et al. 2014; Seuffert & Martín 2017). Human snail management also influences population levels.

Female Golden Apple Snails are larger than males (PhilRice 2001; Cowie 2002; Estebenet & Martin 2002). Sex was identified by the operculum's shape: concave in females, convex near the margin in males (Xu et al. 2016; Moneva et al. 2012). The observed sex ratio differences highlighted abundant egg clutches in the first sampling, while the lower numbers in the second may have resulted from reduced food availability, seedling maturity, pre-harvest conditions, and the absence of stable leaf sheaths or stems suitable for egg laying. Temperature could also influence this variation. Yusa & Suzuki (2003) reported a typical sex ratio of around 0.5, suggesting a balance between the sexes, but Yusa (2004) notes that some clutches may produce predominantly one sex. Environmental factors (Estebenet & Martin 2002; Gilal & Muhamad 2020) can affect sex ratios. This study's observations support these findings, corroborating the view that environmental conditions influence sex ratio traits.

Snail habitat preferences varied between sampling periods. Adults favored water, leaf sheaths, and sediment, while juveniles mainly occupied leaf sheaths and sediment. Snails prefer to lay eggs on rice seedling leaf sheaths, avoiding submerged clutches, likely due to water's negative effects on eggs and hatching. Habitat use across stages matches that reported in prior studies (Horn et al. 2008). Horn et al. (2008) reported that *Pomacea* spp. Depend on aerial incubation. Submerging eggs can hinder hatching as they may not develop fully or disintegrate. This lack of underwater structural integrity reduces hatching success. GAS prefer to oviposit on firm, aerial substrates like stems, leaf sheaths, rocks, or artificial structures (Horn et al. 2008). This explains the high number of egg clutches on rice seedling leaf sheaths during sampling, as they support egg deposition. Chistopolsky et al. (2023) and Pizani et al. (2005) also found that prolonged water exposure harms embryo development by reducing oxygen and causing early hatching.

Environmental factors significantly influence GAS abundance. Ito (2002) found that pH, dissolved oxygen, and water depth affected overwintering success, while temperature and water velocity did not. Barnes et al. (2008) highlighted that reproductive success depends mainly on temperature and other environmental factors. Bernatis et al. (2016) and Byers et al. (2013) noted pH levels of 5.5 to 9.5 and high humidity support *P. canaliculata* and other Pomacean species, while pH below 5.5 harms growth and survival (Gilal & Muhamad 2020). Elevated humidity and nocturnal rain increase egg oviposition (Teo 2004). Humidity allows snails to stay outside water longer without drying, aiding dispersal (Mueck et al. 2018). Bernatis et al. (2016) observed that over 80% humidity enables adult snails to survive a year on moist sand, versus only 154 days below 60%. Ramakrishnan (2007) showed adults and juveniles survive 70 days at 30℃ with over 95% humidity, and at 20–25 ℃ for at least 308 days in 75–95 % humidity, with juveniles desiccating faster. These data align with the second sampling, which recorded high snail densities due to favorable pH and humidity. In summary, the physicochemical factors—temperature, pH, humidity, and water depth—significantly influenced GAS abundance and habitat preferences, with favorable conditions correlating with higher GAS abundance and habitat preferences.

The ethnobiological data showed all respondents knew GAS, called 'rambuwan' in Meranao. They said its spread was due to both intentional and natural processes. It was introduced to the Philippines as food, a dietary protein source, and an income resource for farmers (Joshi et al. 2001; Joshi 2005b). Respondents described GAS feeding mechanisms and damage to rice crops, yields, health, and livelihood. Rambuwans crawl upward, feeding by nipping or scraping rice seedlings. According to Cummins & Klug (1979), *P. canaliculata* is a scraping, shredding, and collecting feeder. Juvenile snails have higher specific ingestion rates than adults, regardless of feeding mechanism or type consumed (Tamburi & Martin 2009). Young rice seedlings, especially those transplanted 18 to 21 days after sowing, are most vulnerable to snail attacks, as noted by Litsinger & Estano (1993) and Teo (2003). Crop damage correlates with the age of rice plants and snails, with high infestation indicated by reduced plant populations, missing plants, and floating leaf fragments, which are signs of damage to newly transplanted rice (Joshi et al. 2001; Teo 2003).

The spread of GAS posed serious threats to human health. GAS is linked to health risks, including skin irritation as an intermediate host for trematodes (Naylor 1996) and digestive infections (Halwart 1994; Naylor 1996). It can also carry *Angiostrongylus cantonensis*, the rat lungworm, which infects humans and can cause fatal eosinophilic meningoencephalitis (Kim et al. 2014; Song et al. 2016). Chemical control methods against GAS often involve persistent organotin compounds, which can cause nail loss, skin issues, blurred vision, and blindness (Sousa et al. 2013). Research shows some *Pomacean* species carry *Schistosoma mansoni* cercariae, causing schistosomiasis (Cantanhede et al. 2014). Transmission usually occurs via infected gastropods like *P. canaliculata*, which act as intermediate hosts (Kim et al. 2014). Schistosomiasis is endemic in parts of the Philippines, especially the southern islands, including the study area, where parasitic infestations are common (Olveda et al. 2014). To control invasive *Pomacea* species globally, various measures have been tested (Joshi 2005b). Effective management needs regulation and education to reduce harm, protect yields, and prevent spread (Schneiker 2016). Eradicating invasive species like GAS is very difficult (Joshi 2005b). Various control measures—cultural, mechanical, and chemical—have been tried to reduce *Pomacea* populations below economic thresholds. However, no method or combination is consistently effective, and the effects on crop yield are uncertain (Byers et al. 2013). An integrated strategy remains the best approach to control *Pomacea* spread.

Traditional methods reported include manual removal of eggs and snails, constructing wire-mesh grills and ditches, and managing irrigation water. Hand-picking remains the most effective non-chemical control for GAS despite being labor-intensive (Joshi 2005b; Kunimoto & Nishikawa 2008; Penaredondo et al. 2015; Constantine et al. 2023). Egg collection improves when sticks are used to encourage oviposition (Cowie 2002). Water management, such as lowering water levels before hand-picking, is effective. Proper irrigation reduces snail mobility (Teo 2003; Wada 2004; Arfan et al. 2017). Deeper ditches in rice paddies help collect snails, which congregate when fields drain (Cowie 2002; Joshi 2005b). Ducks are used to reduce snail populations, but effectiveness depends on the timing of release (Halwart 1994; Teo 2003; Joshi 2005b; Vega et al. 2007; Liang et al. 2014).

Modern synthetic chemical pesticides are common due to their convenience. Local products include timpla (mixture), ukap (Magnum), Surekill, Furadan, tupordi (2-4 D), and Machete. These chemicals act as pesticides, molluscicides, herbicides, and insecticides. Furadan, used for over a century, is highly toxic (Stevens 2003). Recently, molluscicides containing niclosamide and metaldehyde have been preferred for field use (PhilRice 2001). Metaldehyde bait remains effective during heavy rain thanks to slow release (PhilRice 2001; Wada 2004). Despite their popularity, chemical pesticides are costly, causing crop damage and incurring expenses for purchase and manual snail removal (Joshi 2005b). Sustainable farming practices are vital to mitigate GAS damage (Schneiker 2016). Developing low-cost, effective, and environmentally sound management strategies is still challenging (Joshi 2005b).

While this study provides baseline ecological and ethnobiological insights into *P. canaliculata* in Lanao del Sur's rice communities, it has limitations that shape future research directions. Conducted at one site and over two sampling periods, the findings cannot be generalized across different times and locations. Physicochemical data were mainly descriptive, and sex determination was based on morphology. Ethnobiological data came from purposively selected male farmers, which may not represent the broader community or disentangle ecological and social factors. Future research should involve multi-season and multi-site studies to examine abundance and habitat-use consistency across larger rice areas. Controlled experiments are needed to assess how water depth, crop stage, humidity, and substrate affect snail activity, reproduction, and crop damage. Interdisciplinary research should include diverse farmer groups, evaluate stage-specific control strategies, and investigate whether health risks and management barriers impact ecology, economy, and public health. Sustainable management should incorporate alternative solutions that do not add financial burdens, emphasizing government and local initiatives to deliver cost-effective, tailored mitigation strategies.

## CONCLUSIONS

The study found that Golden Apple Snail is abundant in both water and sediment during its adult and juvenile stages, where it mates and searches for submerged food sources. Egg clutches are primarily attached to leaf sheaths, providing a safe site for deposition. Favorable environmental conditions further increase snail density and dispersion, thereby influencing both abundance and habitat preferences.

Moreover, the study revealed that the presence of this invasive pest poses a significant threat to local rice farmers, by affecting their livelihoods, health, and production stability. Although traditional practices and modern synthetic pesticides have been used to control pests, these approaches were largely inefficient when applied in isolation. The findings therefore underscore the need for an integrated pest management (IPM) strategy that combines habitat-based monitoring, timely removal of egg clutches, improved field sanitation, water and vegetation management, and judicious use of chemical control only when necessary. Major barriers to effective management included limited financial support, inadequate farming practices, and insufficient education on affordable and safe control measures. Health concerns such as schistosomiasis, colds, and physical injuries were also prevalent. These findings highlight that GAS infestation is not only an agricultural concern but also a rural livelihood and public health issue with broader implications for food security, environmental sustainability, and community well-being.

The researchers therefore strongly advocate for increased government support for disadvantaged farmers through seminars, targeted initiatives, and extension services that promote practical IPM adoption. The public health sector should also take a more active role in educating farmers and local communities about the health risks associated with snail handling and consumption. Likewise, community-level collaboration can strengthen surveillance, coordinated control, and long-term sustainable management. Future research should focus on developing locally appropriate and cost-effective IPM strategies, including ecological, mechanical, and community-based interventions suited to rice-farming communities.

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