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Bio-inventory of terrestrial gastropod species in Northern Mindanao, Philippines

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Abstract. *Tañan VB, Sumaya NHN. 2024. Bio-inventory of terrestrial gastropod species in Northern Mindanao, Philippines. Biodiversitas 25: 3391-3402.* Gastropods are the largest class in the phylum Mollusca, with an estimated 70,000 to 76,000 species. The prevalence of gastropods is undeniable evidence of their successful adaptation to various habitats, including terrestrial, freshwater, and marine environments. Slugs and snails are extremely effective in the terrestrial environment, where they are involved with several ecological activities such as nutrient recycling, decomposing waste material, and calcium enrichment in calcium-deficient habitats. However, many species (notably the non-indigenous ones) are well-known pests that damage crops, increase pesticide demand, harm natural ecosystems, reduce native biodiversity, and even carry pathogens and parasites. Northern Mindanao is one of the regions in Mindanao, Philippines, with abundant agricultural resources. In comparison to other taxa in Mindanao, gastropod species have received less attention from researchers. Thus, we collected, characterized, and delineated species of gastropods from the different agricultural areas in Northern Mindanao, Philippines. During sampling, environmental parameters were recorded, and it was established which gastropod species are associated with crops and, at their worst, can become pests to banana (*Musa acuminata* Colla), corn (*Zea mays* L.), cabbage (*Brassica oleracea* L.), carrots (*Daucus carota* L.), rice (*Oryza sativa* L.), eggplant (*Solanum melongena* L.), chayote (*Sechium edule* (Jacq.) Sw.), radish (*Raphanus sativus* L.), and many more. Morphology and morphometrics following published protocols on the collected organisms successfully characterized the gastropod species. Slug species, namely, *Laevicaulis alte* (Férussac, 1822), *Sarasinula plebeia* (P.Fischer, 1868), and *Deroceras (Deroceras) laeve* (O.F.Müller, 1774) and snail species, *Lissachatina fulica* (Férussac, 1821), *Pomacea canaliculata* (Lamarck, 1822), *Subulina octona* (Bruguière, 1789), *Oxychilus (Ortizius) alliarius* (J.S.Miller, 1822), and *Bradybaena similaris* (A.Férussac, 1822), were identified. The study reveals that exotic terrestrial gastropods are prevalent in the agricultural areas across Northern Mindanao. Consequently, additional surveys are necessary to determine the extent of their dispersal, crop preferences, pest status, and to its associated parasites within the Philippines.

Keywords: Eupulmonata, Mollusca, morphometrics, Stylommatophora

INTRODUCTION

Class Gastropoda is a highly diverse phylum within the Phylum Mollusca, with around 70,000-76,000 described species, including 25,000 terrestrial species worldwide (Moraitis et al. 2018; Rosenberg 2014). Gastropods are known for their vast diversity, spanning across various habitats but have received little attention regarding their distribution compared with other taxa (Kesner and Kumschick 2018). The gastropod species are found in a wide range of environments, including terrestrial, freshwater, as well as in marine habitats (Bidat et al. 2023). Moreover, gastropods play a vital role in the functioning of ecosystems (Loke and Chrisholm 2022; Gheoca et al. 2023), providing essential nutrients and food to wildlife and contributing to the structure of plant communities (South 1992; Ghosh et al. 2017).

Snails and slugs are successful gastropods in the terrestrial ecosystem wherein the latter is typically identified by their lack of external shell or reduced shell size (South 1992; Barker 2002; Barua et al. 2021). Slugs and snails, comprising 80% of species diversity, are hermaphrodites, possessing both male and female reproductive organs for self-fertilization, enabling greater adaptability in challenging environments (Zając and Kramarz 2017). Terrestrial gastropods, despite being considered pests, contribute to litter decomposition and play a role in plant disease control in agroecosystems (Neubert et al. 2019). Additionally, the International Union for Conservation of Nature (IUCN) Red List https://www.iucnredlist.org (Accessed: July 08, 2024) reports that 1105 species of terrestrial gastropods are either extinct, critically endangered, endangered, or vulnerable worldwide, with many more listed at local and national levels.

Terrestrial slugs are prevalent in tropical areas, yet they are less frequently collected compared to snails (Rowson et al. 2017). The slug taxa originated independently from many lineages of land snails that gradually lost their shells through a process known as limacization, making terrestrial slugs a non-monophyletic group (Ramos et al. 2021). Slugs have been identified as one of the successful pest groups due to the loss of their shell, which also allowed for increased movement and less reliance on calcium (Nicolai and Ansart 2017; Ramos et al. 2021). The slug body plan is found in the Eupulmonata clades of Stylommatophora (land snails and slugs) and Systellommatophora (aquatic and terrestrial slugs) (Schrodl 2014).

Terrestrial snails are classified into two major groups: the Eupulmonata and the Caenogastropoda, which include the majority of prosobranch species (Sosa et al. 2014; Bouchet et al. 2017). Terrestrial snails are involved in a variety of ecosystem processes, including pollination, nutrient recycling, decomposing detritus and plant material, calcium enrichment in calcium-deficient habitats, soil generation, and providing food for other species (Astor et al. 2015; Zaidi et al. 2021). Additionally, they are good bioindicators due to their sensitivity to environmental variables and typically restricted capacity to disperse (Nurinsiyah et al. 2016; Hodges and McKinney 2018). Furthermore, many gastropod species (notably the introduced species) are notorious pests that cause crop loss, pesticide spread, harm to natural ecosystems, and a decline in native biodiversity (Barker 2002; Curry et al. 2016; Das and Parida 2015). In light of the significance of these organisms, this research investigates the gastropod species in the agricultural areas in the four provinces in North Mindanao, Philippines. We collected, evaluated, and characterized the gastropod species found in the agricultural areas of this region.

MATERIALS AND METHODS

Establishment of sampling areas

A purposive sampling of terrestrial gastropods was done on sixteen agricultural areas across the four provinces of Northern Mindanao, Philippines (Figure 1). The study was conducted from September to November 2022, with eight participants at each site for an hour during early morning (5:30 to 9:00 am) and dusk (4:30 to 6:30 pm) hours, when gastropods are most active. A travel permit was obtained before the fieldwork to comply with COVID-19 pandemic protocols. In addition, the authors sought approval from the farm owners. Northern Mindanao serves as an appropriate reference for biodiversity assessments of terrestrial gastropods on the agricultural areas due to their abundance, diversity, comprehensive taxonomic information, and representation. According to the Philippine Statistics Authority (https://psa.gov.ph/ accessed November 14, 2022), 52.2 percent of the region's total land area was made up of agricultural land. These chosen provinces are known to produce vast amounts of crops namely, banana (*Musa acuminata* Colla), corn (*Zea mays* L.), cabbage (*Brassica oleracea* L.), carrots (*Daucus carota* L.), rice (*Oryza sativa* L.), eggplant (*Solanum melongena* L.), chayote (*Sechium edule* (Jacq.) Sw.), radish (*Raphanus sativus* L.), and many more providing the demand in local and international markets (Layug and Montinola 2016).

Physicochemical parameters

Certain environmental characteristics were determined to gain an understanding of the area where the gastropods are found. Weather conditions, air and soil temperatures, soil moisture, soil pH, relative humidity, soil texture as well as elevation were recorded. A 4-in-1 soil tester was placed 5cm deep into the soil to test for soil temperature, moisture, and pH, while a hygrometer was positioned in the air to calculate Relative Humidity (RH). A qualitative identification of the soil texture was also made by classifying it as sand, sandy loam, and clay loam following the protocol by Aranico et al. (2014). Considering that some parts of these provinces are situated in a mountainous location, elevation was calculated based on sea level, which is the surface of the sea with the elevation set to 0 feet (0 m) using the GeoCamera program.

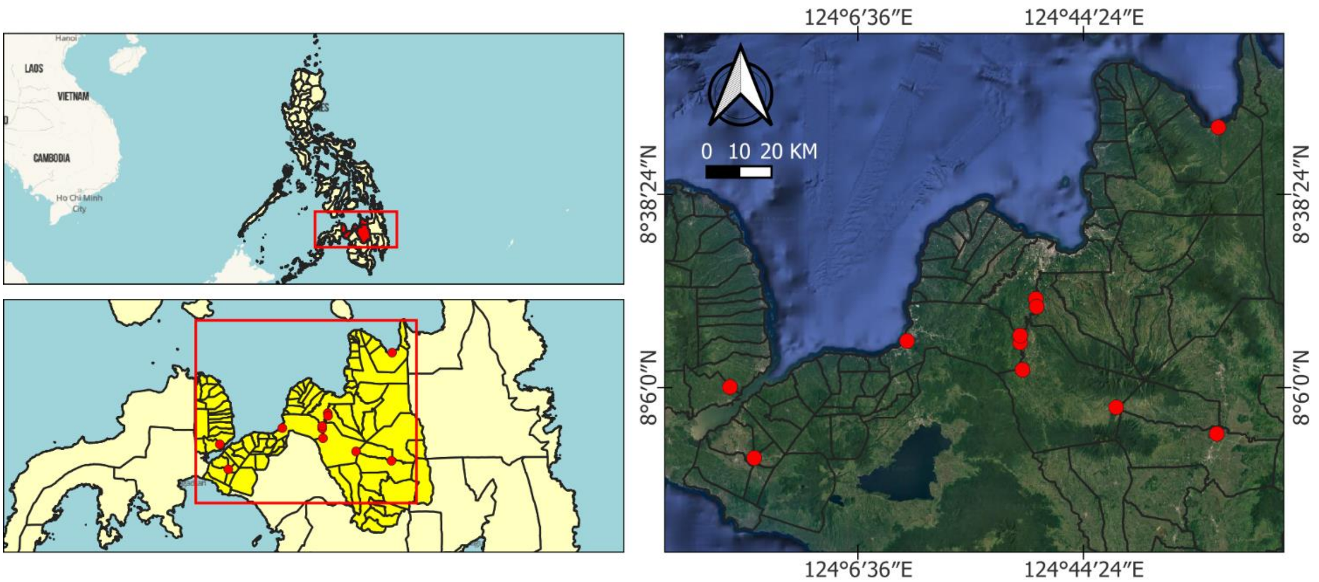

Figure 1. Map showing the sampling sites of terrestrial gastropod species in the selected areas of Mindanao, Philippines

Slug morphological and morphometric analysis

Terrestrial gastropods, both slugs and snails, were cleaned from debris under running water, placed in a plastic containers, and transported to the Flora and Fauna Biodiversity Laboratory (FBL), Premier Research Institute of Science and Mathematics (PRISM) in Mindanao State University-Iligan Institute of Technology (MSU-IIT), Tibanga, Iligan City, Philippines for observation, identification, and as voucher specimens with collection number 032022SCC.

The mixed species of terrestrial gastropods were morphologically characterized following the published techniques and keys provided by Mc Donnell et al. (2009) - “Slugs: A Guide to the Native and Invasive Fauna of California”, Smith and Kershaw (1979) - “Field guide to the non-marine molluscs of Southeastern Australia”, and by Fiedler (2019) - “Guam Land Snail ID Booklet a Simple Guide to Terrestrial Gastropods of Guåhan”. Morphological characteristics specifically body colors, patterns, patches, stripes, and the shape of the mantle, were recorded as part of the study's comprehensive examination. Body length was measured from anterior to posterior tip, mantle length, body width which is the widest part of the body, and live weight in grams using electronic digital balance (0.001g) (Das and Parida 2015). These measurements were taken in accordance with Figure 2 to guarantee the reliability and consistency of the data gathered.

Snail morphological and morphometric analysis

The snail specimens underwent a comprehensive morphological assessment, with careful observation of their shell size, color, and patterns. To further examine their conchological characteristics, the study conducted meristic measurements, including shell length, shell height, spire length, number of whorls, aperture length, and aperture height as depicted in Figure 3. To obtain precise measurements, the snail samples were carefully inverted with their aperture facing upward, allowing for the accurate measurement of the desired parameters. Shell length was measured from the shell's apex to the base of the aperture, while shell height was measured at the widest point of the shell up to the outermost side of the aperture. Spire length was determined by measuring the apical whorls excluding the main whorl, and the whorl number corresponded to the number of complete turns of the whorls, following the methods established by Galan et al. (2015). The aperture length and height were also measured representing the distance between the two widest points of the aperture. Weights of the live snails were also recorded using the electronic digital balance. The researcher took all the measurements using a vernier caliper to ensure the accuracy and consistency of the data collected.

RESULTS AND DISCUSSION

Purposive sampling reveals that terrestrial gastropods were found devouring crops and in large numbers, thus becoming devastating pests. Grayscale representations of the terrestrial gastropods' presence are displayed in Figure 4. Exact locations with the area codes and environmental parameters in the sampling areas for terrestrial gastropod collection were recorded and are listed in Table 1. The region is home to three exotic slug species, namely, *Laevicaulis alte* (Fèrussac, 1822), *Sarasinula plebeia* (Fischer, 1868), and *Deroceras laeve* (Muller, 1774) which is the first record in the Philippines. Four exotic species of snails, namely *Lissachatina fulica* (Fèrussac, 1821), *Pomacea canaliculata* (Lamarck, 1822), *Oxychilus (Ortizius) alliarius* (J.S.Miller, 1822), *Subulina octona* (Bruguière, 1789), and a native snail, the *Bradybaena similaris* (A.Fèrussac, 1822) was identified.

Terrestrial gastropod morphological and morphometrics analysis

Morphometric assessments on the collected gastropods were carried out to support the identification of the species based on their unique morphologies. Tables with the results are presented below for a clearer comparison. The data is presented in units of millimeters (mm) and grams (g) and expressed as mean±standard deviation (range) to account for variations within the samples.

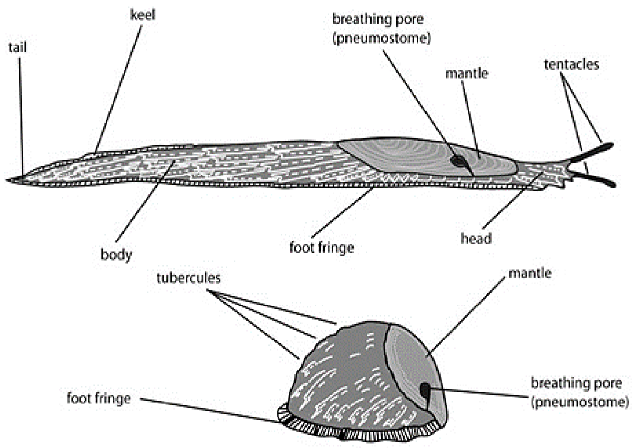

Figure 2. Diagram of expanded (above) and contracted (below) slugs with the labels of the morphological characteristics. University of Florida Entomology and Nematology of Capinera 2018.

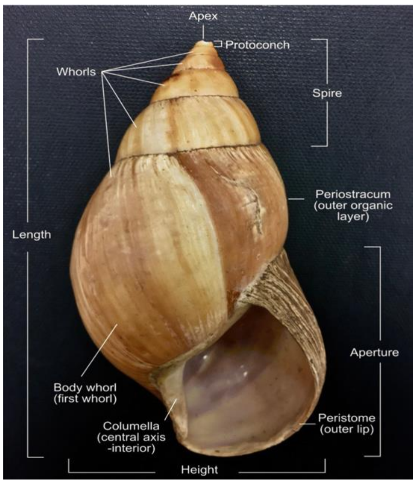

Figure 3. The measurement standards of the growth indexes for snails. African Archaeological Review of Miller et al. (2018)

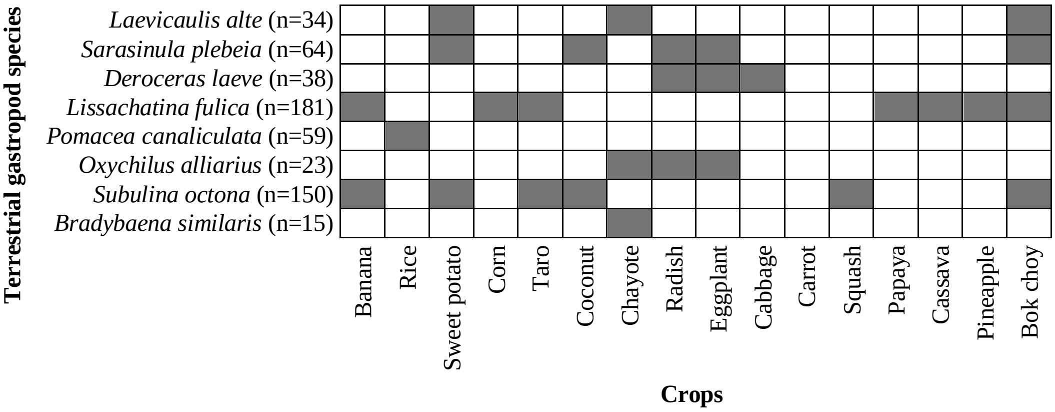

Figure 4. The bipartite graph of species of snails and slugs and their associated microhabitats (crops). The upper level presents the various gastropod species and the lower-level correlates to the favored microhabitats

Slug species characterization

Laevicaulis alte also known as tropical leatherleaf slug was collected from the plantation of bok choy, sweet potato, chayote, and carrot farms in Bukidnon as shown in Figure 5. *L. alte* originates from Africa but has been introduced to southern Asia, Australia, and many Pacific Islands (Das and Parida 2015). It is a dark-colored slug with a distinct central keel, which is a thin, pale brown longitudinal line that runs along the dorsal side. The body of *L. alte* is flattened dorsally and ventrally with a slightly granulated appearance. On the head, there is a smaller pair of bilobed, inconspicuous tentacles and posterior anus. The mantle chamber and pneumostome are absent in this slug. The mucus secreted along the slime path is clear, and the eggs are white. A total of 34 *L. alte* with an average body length of 72.96 mm was collected. Other morphometric observations were summarized in Table 2.

Sarasinula plebeia also known as the Caribbean leatherleaf slug is present throughout the four provinces of Northern Mindanao. *S. plebeia* originally originated in Central America and has now expanded throughout the world, inhabiting America, the Pacific, and the Philippine islands (Dalan et al. 2023). A total of 64 *S. plebeia* were collected, morphometric observation was shown in Table 3. *S. plebeia* is relatively big and is generally light to dark brown in appearance, and two sets of tentacles emerge from the head as shown in Figure 6. The body is flat and elongates when slides, foot runs in a narrow line between the hyponotum and perinotum from the anterior to posterior end of the body. When the slug is dormant, the tentacles are hidden beneath the notum. The pneumostome is very small and located under the notum.

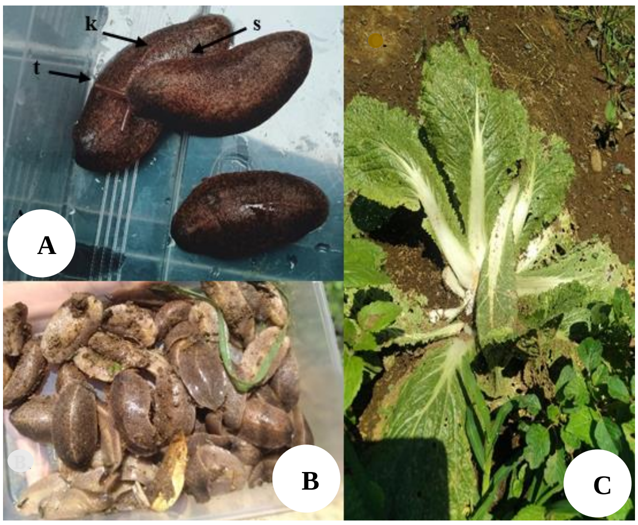

Figure 5. *Laevicaulis alte* in bok choy plantation (A) adult slug: t-eye bearing tentacles, k-keel, and s-dark colored tuberculated skin; (B) slugs found in just one plot; and (C) holes on bok choy leaves caused by *L. alte*

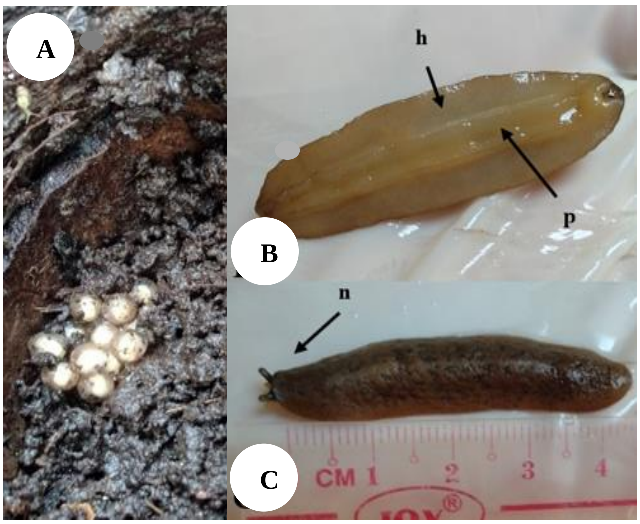

Figure 6. *Sarasinula plebeia* stages. (A) eggs; (B) ventral part of the whole slug: p-perinotum, h-hypernotum; and (C) whole notum with visible ocular tentacles-ot

Table 1. Environmental parameters on the sampling areas of terrestrial gastropods in Northern Mindanao, Philippines

Prov.	Location/area code/coordinates	Gastropods	Elevation ft (m)	Weather condition	Relative humidity	Air temp.	Soil temp.	Soil pH	Soil type	Soil moisture
Lanao del Norte	Cathedral, Kapatagan-CKL (7.8721N, 123.7738E)	*Sarasinula plebeia* (P.Fischer, 1868)	101 (30.78)	Sunny	79%	28°C	24°C	4.5	Muddy	24 %
		Subulina octona (Bruguière, 1789)		Sunny	81%	29°C	24°C	4.5	Loamy	18 %
		Lissachatina fulica (Férussac, 1821)		Sunny	81%	29°C	26°C	6.5	Loamy	19 %
	San Vicente, Kapatagan-SVL (7.8849N, 123.7744E)	*Pomacea canaliculata* (Lamarck, 1822)	54.1 (16.48)	Cloudy	76%	27°C	24°C	6.5	Muddy	25 %
		Lissachatina fulica (Férussac, 1821)		Cloudy	76%	28°C	25°C	6.5	Loamy	21 %
		Subulina octona (Bruguière, 1789)		Cloudy	76%	28°C	25°C	6.5	Loamy	20 %
	San Manuel, Lala-SML (7.9074N, 123.8153E)	*Pomacea canaliculata* (Lamarck, 1822)	32.4 (9.87)	Sunny	78%	29°C	24°C	6.5	Muddy	24 %
		Lissachatina fulica (Férussac, 1821)		Sunny	75%	26°C	27°C	6.5	Loamy	17 %
		Subulina octona (Bruguière, 1789)		Sunny	75%	27°C	28°C	6.5	Loamy	18 %
	Baroy-BRL (8.0256N, 123.7789E)	*Lissachatina fulica* (Férussac, 1821)	67.6 (20.6)	Cloudy	77%	28°C	25°C	7.5	Loamy	18 %
	Iligan City-ICL (8.2286N, 124.2381E)	*Oxychilus (Ortizius) alliarius* (J.S.Miller, 1822)	860 (262.12)	Sunny	82%	28°C	26°C	7.5	Loamy	20 %
Bukidnon	Bagontaas, Valencia-BVB (7.5711N, 125.542E)	*Lissachatina fulica* (Férussac, 1821)	1,055.4 (321.68)	Cloudy	80%	28°C	26°C	6.5	Loamy	20 %
		Sarasinula plebeia (P.Fischer, 1868)		Cloudy	81%	29°C	26°C	6.5	Loamy	22 %
		Subulina octona (Bruguière, 1789)		Cloudy	80%	28°C	24°C	6.5	Loamy	21 %
	Kibangay, Lantapan-KLB (8.0463N, 124.8870E)	*Laevicaulis alte* (Férussac, 1822)	3,939.9 (1.200.88)	Sunny	76%	28°C	27°C	6.5	Loamy	23 %
		Lissachatina fulica (Férussac, 1821)		Sunny	76%	28°C	27°C	6.5	Loamy	21 %
	Lirongan, Talakag-LTB (8.0530N, 124.8297E)	*Sarasinula plebeia* (P.Fischer, 1868)	4,629.9 (1.411.19)	Sunny	75%	28°C	25°C	6.5	Loamy	22 %
		Oxychilus (Ortizius) alliarius (J.S.Miller, 1822)		Sunny	78%	29°C	28°C	6.5	Loamy	23 %
	Dagumbaan, Talakag-DTB (8.1486N, 124.5925E)	*Lissachatina fulica* (Férussac, 1821)	1,780.2 (542.6)	Sunny	75%	27°C	26°C	4.5	Loamy	19 %
		Subulina octona (Bruguière, 1789)		Sunny	77%	28°C	25°C	4.5	Loamy	19 %
Misamis Oriental	Tignapoloan, Cagayan-TCM (8.28508N, 124.58588E)	*Lissachatina fulica* (Férussac, 1821)	1,495.7 (455.88)	Sunny	63%	26°C	25°C	6.5	Loamy	20 %
		Subulina octona (Bruguière, 1789)		Sunny	63%	26°C	25°C	6.5	Loamy	18 %
	Dansolihon, Cagayan-DCM (8.3090N, 124.5846E)	*Sarasinula plebeia* (P.Fischer, 1868)	880.9 (268.49)	Cloudy	81%	29°C	27°C	6.5	Loamy	21 %
		Lissachatina fulica (Férussac, 1821)		Cloudy	76%	27°C	26°C	6.5	Loamy	19 %
		Subulina octona (Bruguière, 1789)		Cloudy	76%	27°C	26°C	6.5	Loamy	19 %
	Gingoog-GHM (8.3090N, 124.5846E)	*Deroceras laeve* (Muller, 1774)	1,562 (476.09)	Sunny	63%	26°C	25°C	6.5	Loamy	23 %
	Claveria-CMM (8.28508N, 124.58588E)	*Lissachatina fulica* (Férussac, 1821)	3,073.1 (936.68)	Sunny	81%	29°C	27°C	6.5	Loamy	22 %
		Deroceras laeve (Muller, 1774)		Sunny	76%	27°C	26°C	6.5	Loamy	20 %
		Bradybaena similaris (A.Fèrussac, 1821)		Sunny	76%	27°C	26°C	6.5	Loamy	20 %
Misamis Occidental	Calacaan, Plaridel-CPMO (8.6145N, 123.7093E)	*Pomacea canaliculata* (Lamarck, 1822)	25.9 (7.89)	Sunny	73%	28°C	24°C	6.5	Muddy	22 %
		Lissachatina fulica (Férussac, 1821)		Sunny	74%	29°C	24°C	6.5	Loamy	20 %
	Buenavista, Bonifacio-BBMO (8.0999N, 123.6126E)	*Sarasinula plebeia* (P.Fischer, 1868)	1,312 (399.89)	Cloudy	76%	27°C	24°C	6.5	Loamy	19 %
		Pomacea canaliculata (Lamarck, 1822)		Cloudy	76%	28°C	25°C	6.5	Muddy	18 %
		Subulina octona (Bruguière, 1789)		Cloudy	76%	28°C	25°C	6.5	Loamy	20 %
	Capalaran, Tangub-CTM (8.1143N, 123.7440E)	*Lissachatina fulica* (Férussac, 1821)	524.6 (159.89)	Sunny	78%	29°C	24°C	6.5	Loamy	19 %
		Subulina octona (Bruguière, 1789)		Sunny	75%	26°C	27°C	6.5	Loamy	20 %

Table 2. Morphometrics of *Laevicaulis alte* from LTB, Bukidnon, Philippines. Data are expressed in mean±standard deviation (range). All morphological characteristics measurements are in millimeters (mm) and weight in grams (g)

Slug species	Body length	Body width	Central keel	Live weight (g)
L. alte LTB (n=34)	72.96±11.27 (61.00-83.4)	35.73±3.57 (28.7-39.1)	65.77±4.59 (57.8-68.3)	8.56±1.22 (7.24-10.3)

Table 3. Morphometrics of *Sarasinula plebeia* from area codes CKL, BVB, LTB, and DCM. Data are expressed in mean±standard deviation (range). All morphological characteristics measurements are in millimeters (mm) and weight in grams (g)

Slug species	Body length	Body width	Notum	Live weight (g)
S. plebeia CKL (n=15)	59.43±3.49 (54.7-65.8)	10.12±2.78 (6.5-14.0)	57.08±3.38 (51.8-63.3)	1.69±0.19 (1.08-1.46)
S. plebeia BVB (n=12)	55.32±5.97 (44.8-64.8)	9.27±2.67 (5.8-13.9)	53.14±5.86 (42.6-61.7)	1.53±0.15 (1.34-1.76)
S. plebeia KLB (n=14)	54.37±5.57 (45.9-64.4)	9.52±2.89 (4.9-14.6)	51.98±5.59 (42.7-62.3)	1.57±0.19 (1.43-1.73)
S. plebeia DCM (n=10)	55.68±5.68 (48.4-64.2)	9.95±3.08 (5.2-14.6)	53.29±5.64 (46.5-62.4)	1.68±0.44 (1.35-1.74)
S. plebeia BBMO (n=13)	55.96±6.49 (46.9-63.6)	9.76±3.36 (5.9-13.5)	53.86±6.52 (44.2-62.9)	1.57±0.13 (1.38-1.72)

Table 4. Morphometrics of *Deroceras laeve* from GHM and CMM. Data are expressed in mean±standard deviation (range). All morphological characteristics measurements are in millimeters (mm)

Slug species	Body length	Body width	Head	Mantle	Tail length
D. laeve GHM (n=18)	23.82±3.40 (18.5-31)	6.22±0.80 (5-7)	2.99±0.58 (2.1-3.8)	9.96±1.65 (7.4-13.5)	10.9±1.41 (8.6-14.2)
D. laeve CMM-R (n=10)	23.27±3.18 (18-28)	6.27±0.76 (6.0-7.2)	2.45±0.40 (1.8-2.8)	9.82±1.60 (7.0-12.2)	11±1.35 (10-12.5)
D. laeve CMM-E (n=10)	23.19±2.04 (19-26)	6.42±0.73 (5.0-7.0)	2.25±0.36 (1.7-2.8)	9.73±1.02 (7.4-11.2)	11.21±0.87 (10.0-12.6)

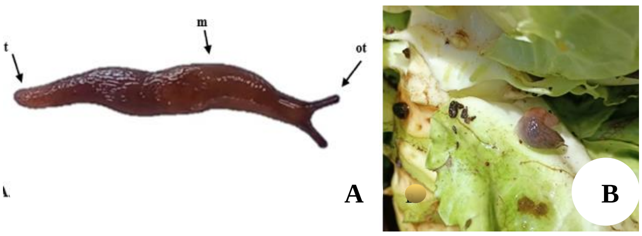

Figure 7. Photographs of *Deroceras laeve* (A) morphological characters ot-ocular tentacle, m-mantle, and t-tail; and (B) a damaged cabbage crop

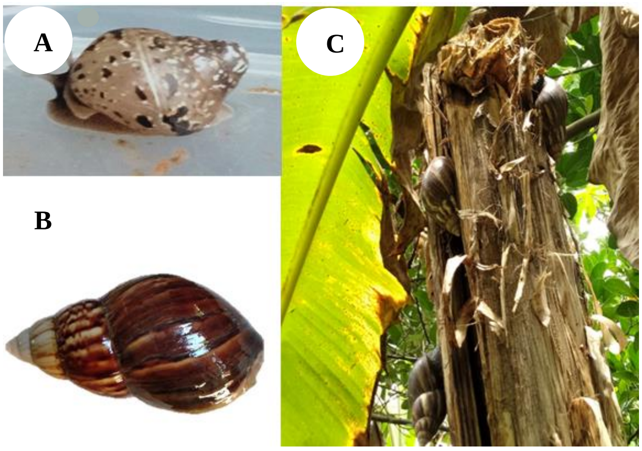

Figure 8. Photographs of (A) young *Lissachatina fulica,* (B) egg-bearing adult, and (C) *L. fulica* on a banana tree

Deroceras laeve also known as marsh slug was collected in the cabbage plantation in Gingoog, Misamis Oriental as shown in Figure 7. *D. laeve* is native throughout Europe and the Arctic (Rowson et al. 2014). Typically, this slug is small and slim with a varying skin color of grayish brown to chocolate brown. The body is cylindrical and has a slight distal width. The mantle is approximately half the length of the body with a delicate frontal wrinkle pattern. In the tail portion, which is smaller than the mantle, a little keel has been seen. A total of 38 specimens of *D. laeve* was recorded and its morphometric observation were listed in Table 4. Furthermore, this serves as the first record of *D. laeve* in the Philippines (Tañan et al. 2024).

Snail species characterization

Lissachatina fulica also known as giant African snail is present throughout Northern Mindanao and mostly present in banana plantation (Figure 8). *L. fulica* is native to the Central Northeast coast of Africa and is found on all continents (Andreazzi et al. 2017). *L. fulica* was easily recognized by its massive size with measurements from 68.05 to 73.96 mm and relatively long, narrow, conical shell. Area codes and a more detailed morphometric observation are listed in Table 5. The snail's shell typically has seven to nine whorls when it is fully developed and mature. Some shells are reddish-brown with pale yellow vertical lines, while others are dark brown or black with dark stripes and streaks that run across the whorls. A total of 181 *L. fulica* was retrieved from the banana, corn, and other crop plantation throughout the region.

Pomacea canaliculata (Lamarck, 1822) also known as golden apple snail is a freshwater gastropod but was included as it is mainly found in the rice paddies throughout the region (Figure 9). *P. canaliculata* originates from North America and was introduced and established throughout Europe and Asian countries (Yang et al. 2018). The shell is thin and smooth, and it has an operculum. Females are larger than males when fully developed. The color ranges from brown to greenish brown to dark chestnut, and there may be varying numbers and thicknesses of dark brown spiral bands. The whorls are spherical, and there are deep channels in the suture between them. In general, the shell spire is small, the interior lip of the shell is unpigmented, and the aperture is typically ovoid to kidney-shaped. A total of 59 specimens of *P. canaliculata* were collected. Its morphological analysis is listed in Table 6.

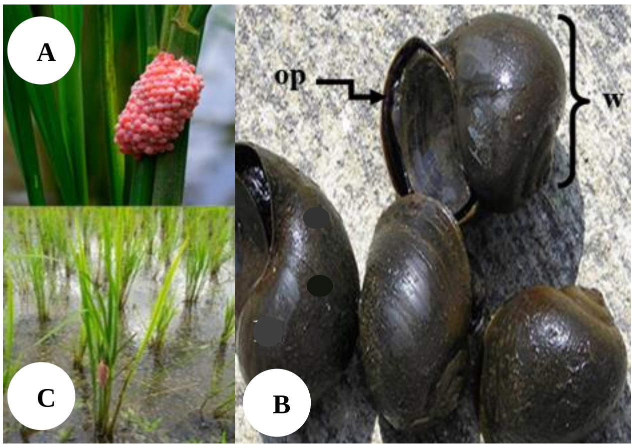

Figure 9. *Pomacea canaliculata* (A) eggs; (B) whole snail: op-operculum, w-whorls; and (C) gaps on rice field

Table 5. Morphometrics of *Lissachatina fulica* from all provinces with the specific area codes. Data are expressed in mean±standard deviation (range). All morphological characteristics measurements are in millimeters (mm)

Snail species	Shell length	Shell height	Spire length	No. of whorls	Aperture length	Aperture height
L. fulica CKL (n=15)	73.62±3.64 (68.7-75.7)	35.24±1.33 (33.2-37.2)	20.31±1.18 (18.6-22.5)	6.8±0.42 (6-7)	41.02±1.06 (39.6-42.9)	25.89±1.00 (26.1-27.7)
L. fulica SVL (n=15)	71.35±5.89 (64.7-76.8)	34.62±1.10 (33.5-37.4)	19.2±0.90 (17.8-20.7)	6.4±0.52 (6-7)	40.49±2.03 (38.6-43.4)	24.13±1.06 (23.1-26.5)
L. fulica SML (n=15)	68.06±1.93 (65.2-71.2)	33.89±0.80 (32.6-35.3)	18.21±1.65 (16.4-21.3)	6.5±0.52 (6-7)	39.13±0.73 (38.3-40.3)	22.85±0.89 (21.5-24.4)
L. fulica BRL (n=15)	73.96±6.75 (66.2-82)	36.1±1.60 (34.2-39.3)	20.24±2.33 (17.2-23.4)	6.6±0.52 (6-7)	41.26±2.11 (38.8-43.4)	25.04±1.11 (23.8-26.4)
L. fulica BVB (n=15)	70.16±4.61 (66.2-76.6)	33.51±1.08 (32.1-35.3)	19.03±1.22 (16.9-20.5)	6.8±0.42 (6-7)	39.96±1.72 (37.7-42.3)	23.41±0.94 (22.1-24.7)
L. fulica LTB (n=15)	69.48±4.36 (64.8-76.3)	33.89±1.11 (32.5-35.0)	18.32±1.65 (16.1-20.5)	6.4±0.52 (6-7)	39.51±1.72 (37.2-42.2)	22.98±0.98 (21.9-24.5)
L. fulica DTB (n=15)	71.41±3.48 (68.4-71.6)	35.24±1.05 (33.6-36.6)	19.42±1.66 (16.7-22.5)	6.8± 0.42 (6-7)	37.87±4.67 (27.8-42.9)	24.64±1.17 (22.3-25.6)
L. fulica TCM (n=15)	71.61±5.72 (62.5-76.8)	35.4±1.29 (34.0-37.6)	19.63±1.76 (17.2-23.3)	6.5±0.52 (6-7)	40.52±1.91 (37.1-42.8)	24.42±1.13 (22.8-26.1)
L. fulica DCM (n=15)	71.35±5.89 (64.7-83.2)	35.04±1.37 (33.1-37.4)	19.78±1.74 (17.8-24.1)	6.6±0.52 (6-7)	40.47±1.85 (38.3-43.9)	24.15±1.11 (23.0-26.7)
L. fulica CMM (n=15)	68.05±5.33 (61.75-73.2)	34.34±1.30 (32.9-37.4)	19.715±0.92 (18.4-20.7)	6.5±0.52 (6-7)	39.34 ±1.52 (37.5-42.0)	22.34±1.58 (19.7-24.5)
L. fulica CPMO (n=14)	69.29±6.78 (62.5-83.4)	33.45±3.33 (32.6-35.3)	18.51±1.90 (15.6-22.0)	6.7±0.47 (6-7)	38.23±1.66 (36.2-41.6)	22.62±0.89 (20.5-23.1)
L. fulica CTM (n=17)	72.29±5.72 (62.4-80.2)	34.92±2.67 (30.2-38.4)	19.06±2.39 (17.7-21.5)	6.7±0.47 (6-7)	40.61±2.64 (37.2-43.8)	22.95±1.88 (20.6-27.8)

Table 6. Morphometrics of *Pomacea canaliculata* with the specific area codes. Data are expressed in mean±standard deviation (range). All morphological characteristics measurements are in millimeters (mm)

Snail species	Shell length	Shell height	No. of whorls	Aperture length	Aperture height
P. canaliculata CKL (n=15)	35.87±3.23 (32.3-41.5)	26.24±2.19 (23.8-30.2)	5±0	10.5±2.20 (9.7-14.8)	13.42±2.82 (11.4-17.0)
P. canaliculata SVL (n=15)	34.77±4.78 (27.3-42.6)	25.08±2.34 (22.5-28.4)	5±0	10.98±1.25 (9.0-12.7)	12.02±1.17 (10.2-13.9)
P. canaliculata CPMO (n=15)	32.02±3.99 (25-39.4)	23.89±2.22 (19.4-26.7)	5±0	10.30 ±1.32 (8.2-12.4)	11.46±1.38 (8.9-12.45)
P. canaliculata BBMO (n=14)	31.30± 3.61 (24.1-38.5)	23.72±2.19 (18.7-26.1)	5±0	10.82 ±1.27 (8.6-12.8)	11.72±1.21 (89.7-13.6)

Oxychilus alliarius also known as garlic snail is found in vegetables including chayote, eggplant, and other vegetable gardens (Figure 10). *Oxychilus alliarius* originates from west and central Europe but has been introduced to several regions worldwide, including North America, Columbia, Chile, Hawaii, Australia, and in Asia (Salvador et al. 2020). *O. alliarius* itself is dark blue (in color) and it is relatively small. The shell is shiny, smooth, and very slightly reddish to greenish (in color). The bottom is frequently more opaque and paler. The shell is made up of 4 to 5 convex whorls, with the last whorl often weakly dropping near the aperture. A total of 23 *O. alliarius* were collected in the crop plantations of chayote, radish, and eggplant. The morphometric observation is summarized in Table 7.

Subulina octona also known as miniature awl snail is a small species of snail that is abundant in all the provinces (Figure 11), found in vegetable gardens. *S. octona* is indigenous in America including the Caribbeans (Brodie and Barker 2012). Alive individuals' range in color from cream to pale yellow. The shell is translucent, long, and thin. The deep sutures separate up to eleven convex whorls, in which the first two to three whorls are the largest. The base of the columella is slightly truncated and has a small and oval aperture. The last whorl of the shell of mature adults frequently reveals many relatively large white eggs in the uterus. A total of 150 *S. octona* was collected from the plantations of banana, sweet potato, taro, bokchoy, and squash. The summarized data of its morphometric observation is listed in Table 8.

Bradybaena similaris also known as golden trampsnail is found in chayote farm in Claveria, Misamis Oriental (Figure 12). *B. similaris* is native to the Southeast Asia and has reached to all continents except the Antarctica (Serniotti et al. 2020). It is a small gastropod species with a round shape shell. The shell is a light brown color and frequently has a single, chestnut stripe at the apex. It is characterized by four fine-spiral shell with one big whorl containing mostly the whole-body mass. There is also a single apical chestnut band sometimes emerges along the growth lines, which are irregular. *B. similaris*' body is dark grey to brown except for the foot bottom, which is light brown (in color). In mature members of this species, there is no barrier on the anterior part and the shell's lip. A total of 15 *B. similaris* was collected. The value for the different conchological measurements is shown in Table 9.

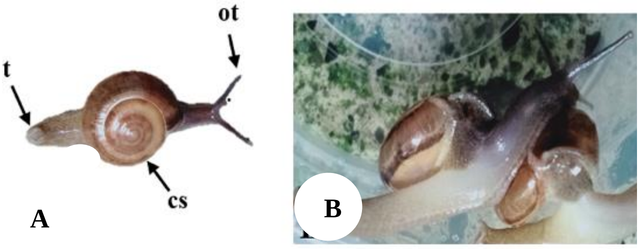

Figure 10. *Oxychilus alliarius.* (A.) whole snail: ot-tentacle, t-tail, and cs-coiled shell; (B.) a stretched snail

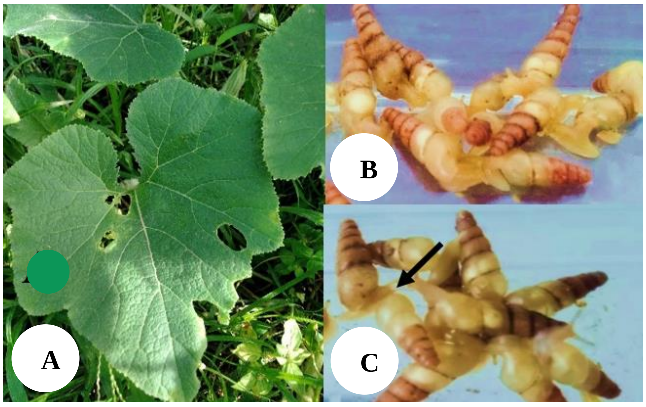

Figure 11. *Subulina octona.* (A) damage caused in the squash garden, (B) whole adult snail, and (C) visible eggs inside its body

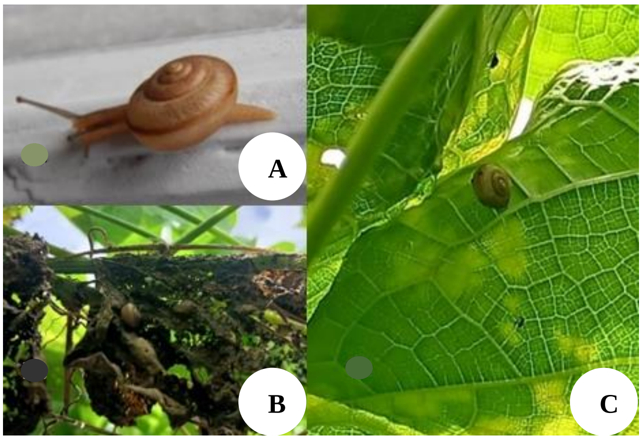

Figure 12. *Bradybaena similaris* on the chayote farm in Claveria, Misamis Oriental, Philippines. (A) whole *B. similaris*, (B) damaged leaves caused by snails, and (C) snail munching a new leaf

Table 7. Morphometrics of *Oxychilus alliarius* from Lanao del Norte and Bukidnon, Philippines. Data are expressed in mean±standard deviation (range). All morphological characteristics measurements are in millimeters (mm)

Snail species	Shell length	Shell height	Spire length	No. of whorls	Aperture height
O. alliarius ICL (n=15)	8.34±0.58 (8.2-9.2)	2.07±0.24 (1.7-2.5)	6.01±0.41 (5.48-6.9)	5±0	1.89±0.31 (1.34-2.1)
O. alliarius KLB (n=8)	8.86±0.63 (8.2-9.7)	2.34±0.27 (2.0-2.7)	6.28±0.39 (5.9-6.9)	5±0	2.28±0.29 (2.0-2.7)

Table 8. Morphometrics of *Subulina octona* from all provinces. Data are expressed in mean±standard deviation (range). All morphological characteristics measurements are in millimeters (mm) and weight in grams (g)

Snail species	Shell length	Shell height	Spire length	No. of whorls	Aperture height
S. octona CKL (n=15)	10.06±0.64 (9.3-1.3)	2.86±0.25 (2.5-3.1)	6.89±0.33 (6.4-7.3)	10.8±0.42 (10-11)	2.63±0.46 (2.0-3.4)
S. octona SVL (n=15)	9.86±1.42 (8.2-13.3)	2.68±0.41 (1.9-3.0)	6.49±0.43 (6.1-7.3)	10.93±0.26 (10-11)	2.67±0.51 (1.8-3.4)
S. octona SML (n=15)	9.88±0.97 (8.7-11.2)	2.81±0.37 (2.2-3.3)	6.84±0.36 (6.2-7.2)	10±0.48 (10-11)	2.71±0.45 (2.0-3.2)
S. octona BVB (n=15)	9.91±1.53 (8.2-13.3)	2.66±0.38 (1.9-3.2)	6.46±0.42 (6.0-7.3)	10.4±0.52 (10-11)	2.69±0.56 (1.8-3.4)
S. octona DTB (n=15)	9.71±1.50 (8.5-13.3)	2.68±0.38 (2.3-3.4)	6.56±0.41 (6.1-7.2)	10.6±0.52 (10-11)	2.7±0.35 (2.3-2.8)
S. octona TCM (n=15)	9.53±1.01 (8.7-10.1)	2.66±0.42 (2.1-3.5)	6.54±0.39 (6.-7.3)	10.7±0.48 (10-11)	2.58±0.40 (2.2-3.3)
S. octona DCM (n=15)	10.04±1.29 (8.5-12.3)	2.79±0.40 (2.2-3.3)	6.85±0.41 (6.2-7.1)	10.8±0.42 (10-11)	2.76±0.42 (2.0-3.4)
S. octona CPMO (n=15)	9.78±1.14 (8.5-11.2)	2.72±0.38 (2.1 - 3.0)	6.73±0.44 (6.0-7.2)	10.87±0.35 (10-11)	2.65±0.39 (1.9-3.0)
S. octona BBMO (n=15)	9.73 ±1.43 (8.4-13.2)	2.8±0.36 (2.3-3.1)	6.56±0.4 (6.1-7.1)	10.8±0.41 (10-11)	2.74±0.34 (2.3-2.9)
S. octona CTM (n=15)	9.63±0.89 (8.7-11.3)	2.69±0.36 (2.2-3.3)	6.69±0.41 (6.1-7.2)	10.5±0.52 (10-11)	2.59±0.42 (2.0-3.2)

Table 9. Morphometrics of *Bradybaena similaris* from CMM-Misamis Oriental, Philippines. Data are expressed in mean±standard deviation (range). All morphological characteristics measurements are in millimeters (mm) and weight in grams (g)

Snail species	Shell length	Shell height	Spire length	No. of whorls	Aperture height
B. similaris CMM (n=15)	13.52±1.53 (11.5-16.45)	13.52±1.53 (11.5-16.45)	9.68±0.89 (8.63-11.4)	5±0	6.08±0.12 (5.72-7.18)

Discussion

Terrestrial slugs and snails are key contributors in the diversity of the terrestrial malacofauna, which is classified as class Gastropoda belonging to the phylum Mollusca. This study discovered seven exotic and a native species of terrestrial gastropods throughout the different provinces of Northern Mindanao. The *L. alte* were found in the farms of sweet potato, chayote, carrots, and radish plantations. *L. alte* is an herbivorous species with a high infestation rate that consumes the vegetation present in its habitat (Das and Parida 2015; Bhavare and Magare 2017). It feeds on living plant tissues, severely damaging field crops, and is regarded as detritus feeders (Ali et al. 2022). *L. alte* had been introduced to several countries in southern and southeastern Asia, including Sri Lanka (Thilakarathne et al. 2024), Nepal (Budha et al. 2015), and was widely distributed in India (Raheem et al. 2014; Tripathy et al. 2018), in addition to other regions like Australia, the Pacific Islands and Hawaiian Islands (Ali et al. 2022).

Another slug, *S. plebeia* was collected across the four provinces of Northern Mindanao. The reproduction of *S. plebeia* is typically high during the rainy season and maturity is attained in about 2.5 months (Alvarez-Cerrillo et al. 2022). It is also a well-known pest in many foreign countries for nursery of mahogany, squash, and sweet potato. This species is a significant species that has spread to the Americas and the Pacific region, including the Philippines (Dalan et al. 2023). This species consumes a wide range of plants as a polyphagous, hermaphrodite herbivore. Due to its non-discriminatory eating behavior as a polyphagous species, it destroys agricultural and horticultural fields and suburban areas worldwide (Bellard et al. 2021; Dueñas et al. 2021). Generally found in moist areas such as below leaf litters and decaying matter to avoid desiccation, they are also shown to burrow in soil with depth ranging from 25 cm to 1 m during the dry season (Alvarez-Cerrillo et al. 2022; Dalan et al. 2023).

The speciose genus *Deroceras* contains at least 123 currently accepted species of terrestrial pulmonate slugs (Anderson 2015). *D. laeve* has a worldwide distribution, establishing themselves in different habitats as agricultural pest and vectors of several diseases (Gupta et al. 2023). Size variation amongst the *D. laeve* population worldwide was observed, especially samples between Asia and the Americas. *D laeve* as the first records in the Philippines for this species, has a 100% similarity both in morphological and molecular characterization with the species from Mexico, Canada, UK, and Vietnam (Dedov et al. 2020). Moreover, the collected live specimens had mantles with proportions unusually large and showed delicate wrinkles visible in front. Overall characteristics are within the range with similar morphological descriptions such as grey to dark-brown live pigmentation, black ocular tentacles, wrinkled mantle, smooth tails, and barely noticeable keel.

The data variations observed can be attributed to several factors such as geographical locations, adaptation strategies, feeding preferences, changes in habitat temperature, and many more (Nicolai and Ansart 2017).

Lissachatina fulica was found mostly in banana farms, burrowing on the body and root of the banana trees as well as crawling on the leaves. *L. fulica* is an African gastropod that has been designated one of the world's 100 worst invasive alien species (Sarma et al. 2015; Miranda et al. 2015). Due to the expansion of the global economy and technological advances in transportation, this species is now common in tropical and subtropical regions on all continents, whether accidentally through agricultural or horticultural products or purposefully as a source of food or as a pet (Silva and Omena 2014). The giant African snail is larger than most other snails, growing to a maximum length of eight inches and a maximum diameter of four inches when mature. *L. fulica* is recognized as a problem in gardens and agriculture (Andreazzi et al. 2017). The species is posing a significant ecological threat due to its high reproductive capacity and herbivorous diet, outcompetently consuming over 50 species of native and agricultural plants. However, the problem is not due these exotic snails, but human-induced environmental degradation, weakening native ecosystems and increasing the risk of non-native species invasion (Cano-Pérez et al. 2021).

Pomacea canaliculata is found on rice paddies. Adults were seen laying eggs in batches which are pink in coloration. *P. canaliculata* has a globular shell with five to six whorls, each of which is connected by a deep suture. The male aperture is rounder than the female aperture, which is big and oval. In contrast, adult females are generally larger than males. According to Tripoli et al. (2015), the operculum is light to dark brown (in color), corneous, concentric, and thick. In many Southeast Asian countries and China, it gradually developed into a devastating agricultural pest of wetland crops (Liu et al. 2019; Wang et al. 2024). *P. canaliculata* destroys a variety of crops, including cereals, fruits, and vegetables resulting in significant annual economic losses due to yield loss, replanting costs, and control expenditures (Marwoto et al. 2020). Its polyphagous feeding preferences, voracious appetite, wide range of environmental adaptation, and rapid development, and high rate of reproduction were all key factors in its successful biological invasion (Seuffert and Martin 2017; Bae et al. 2021). Research revealed *P. canaliculata* to be a crucial intermediate host for the rat lungworm *Angiostrongylus cantonensis* (Chen, 1935), which can infect people and cause angiostrongyliasis characterized as eosinophilic meningitis (Cowie 2017).

Subulina octona are discovered in large numbers in populations in the sampling areas. *S. octona* is small but widely distributed species that has been introduced around the world. Self-fertilization is a viable method of reproduction for this species (Maltz et al. 2017). *S. octona* is 14-17 mm tall, with a straight-sided, narrow, and tapering shell and 9-11 convex whorls divided by a deep suture. The base of the columella is slightly but truncated, the aperture is small and oval, and the outer lip is sharp and simple. The shell is translucent, glossy, and either colorless or yellowish-corneous; growth lines are well-marked, especially on the last whorl. *S. octona* can be found in open habitats as well as ground litter in moist areas in tropical and subtropical forests (D`ávila et al. 2018).

Oxychilus alliarius were found in the vegetable and flower gardens. They are most active during the afternoon to nighttime. The shade of the shell is translucent amber brown on the upper surface and paler on the undersurface. Large, obliquely crescent-shaped, toothless aperture; rounded periphery; umbilicus roughly one-sixth the diameter of the shell. *O alliarius* body is dark gray to blackish, and when handled, it smells strongly of garlic (Holyoak et al. 2022). This species can be found in vegetable and flower gardens, under rocks, in wood, in cellars, in plant material, and around greenhouses. *O alliarius* can be seen all year long, with the peak breeding season taking place in the autumn. They frequently lay little white eggs, which have a diameter of about 1.5 mm. *O alliarius* are native to Western Europe (Wehner et al. 2019). Recent distribution is documented for Colombia, Chile, North America, Greenland, St. Helena, South Africa, Sri Lanka, Australia, New Zealand, and Hawaii which are primarily due to human activity (Nurinsiyah et al. 2016; Wehner et al. 2019).

Bradybaena similaris is a small snail, reaching a length of only 20 to 25 mm when fully grown. They are typically found in moist and shaded areas such as forests, gardens, and agricultural fields that have become invasive. *B similaris* is reported to cause agricultural damage (Naranjo-García and Castillo-Rodríguez 2017) and to feed on a wide variety of plants (Matamoros 2014). Furthermore, parasites like *A. cantonensis* can use *B. similaris* as an intermediary host (Serniotti et al. 2020). Although *B. similaris'* native habitat is most likely in East and Southeast Asia (Hirano et al. 2019), it has expanded to all continents, except for Antarctica, primarily in the tropical and subtropical zones (Serniotti et al. 2020).

Studying exotic terrestrial gastropods in the Philippines is of paramount importance as it allows for the assessment of their vital role in the agricultural sector, identification of existing species, as well as discovery of new introduced ones. Based on the findings of this study, exotic terrestrial gastropods are prevalent in the agricultural fields throughout Northern Mindanao. Hence, more surveys are needed to evaluate the extent of their distribution, crop preferences, pest status, and associated parasites in the Philippines.

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