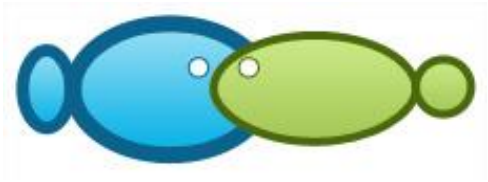

Molluscan fauna in selected freshwater lakes in Mindanao, Philippines

[1]Christine L. Mahinay-Cardente,[2,3,4]Mark A. J. Torres, [2,3]Cesar G. Demayo

[1] Biology Department, Xavier University-Ateneo de Cagayan, Cagayan de Oro City, Philippines; [2] Center of Integrative Health/Climate Change Laboratory, Premier Research Institute of Science (PRISM), MSU-Iligan Institute of Technology, Tibanga Iligan City, Philippines; [3] Department of Biological Sciences, MSU-Iligan Institute of Technology, Tibanga Iligan City, Philippines; [4] School of Interdisciplinary Studies, MSU-Iligan Institute of Technology, Tibanga Iligan City, Philippines. Corresponding author: C. G. Demayo, cgdemayo@gmail.com

Abstract. The present research centers on seminal discoveries regarding molluscan diversity that are associated with lake profile data, including physicochemical factors. For data collection on individuals and water samples, only opportunistic and one-time sampling methods were utilized. The water's physicochemical properties were obtained using a multi-parameter analyzer and subsequently transmitted to a laboratory for further analysis. Numerous lakes are home to mollusk fauna with an exceptionally high species diversity. A total of eight distinct species of freshwater mollusks were discovered. Due to the scale and dense vegetation of Lake Lakewood, seven most abundant species have been identified. *Pomacea canaliculata*, characterized by its high-temperature tolerance and invasive nature, exhibited the most incredible abundance among the observed species. The lake's profile indicates that the expansion and survival of the species were notably impacted. It was determined that Lake Apo and Lakewood contained moderate levels of contamination, while the waters of Lake Holon were spotless. A thorough examination of the species of mollusks and lakes in different seasons, substrates, and water zones should be conducted.
Key Words: bivalve, gastropod, growth, pristine, polluted.

Introduction. Lakes are rich in natural resources, therefore, they serve multiple functions, such as habitats for aquatic life, fish, and wildlife, sources for vital food, and base for recreation. However, lake ecosystems remain fragile: they may incur substantial losses in a variety of functions as a result of rapid environmental fluctuations. While intermittent human intervention may mitigate or even reverse adverse consequences, human activities can exacerbate the rate of change. Due to their capacity to rapidly adapt and assimilate change, lakes are regarded as reliable indicators of global climate change (Adrian et al 2009; Williamson et al 2008). Physicochemical, biological, and physical changes affect the capacity of lakes to maintain existing communities of microorganisms, aquatic vegetation, and animals and to provide ecosystem services (Vincent 2009). Furthermore, in order for lakes to exhibit ecological responses to climate change, they must engage in interactions with a multitude of stressors, including but not limited to water resource management, invasiveness of exotic species, eutrophication, acidification, and hazardous substances (Woodward et al 2010). In order to assess whether the lakes are susceptible to environmental and anthropogenic stress and whether they can serve as indicators of the accelerated rates of climate change, organisms that function as biological indicators should be used for a more comprehensive analysis.

The majority of species employed in bio-assessment programs (Goodwin 2006) and environmental monitoring (Boening 1999; Oehlmann & Oehlmann 2002) are molluscan bivalves and gastropods. Cuadrado (2015) further asserts that these species are considered the most biologically significant indicators in the evaluation of water quality. As a result of their frequent erratic migration, they are highly suitable for discerning impacts that are specific to individual sites. According to Smitha & Mustak (2017), the lake does

not have an acidic environment despite the presence of a large mollusk population, as mollusks become essentially extinct at pH levels above 5 in the natural environment. The natural populations of mollusk species have been subjected to severe ecological constraints due to significant temporal fluctuations in their environment; the ability of a population to withstand these fluctuations is determined by its physiological composition (Frest & Johannes 1999; Lydeard et al 2004). Consequently, the present condition of the waters can be deduced from the existence or absence of particular molluscan species. The reported figures for mollusk inventory, distribution, morphology, and abundance may be considerably underestimated, notwithstanding the considerable size and diversity of this phylum (Strong et al 2008), due to the scarcity of baseline data on these aspects. Lysne et al (2008) posit that the decline in mollusk diversity is influenced by habitat degradation and loss, water contamination, and the introduction of fish and other invasive species. In addition, these exotic species engage in competition with indigenous species for habitat and, at times, sustenance. Moreover, they have the potential to disrupt ecosystem dynamics and introduce novel parasite populations to a given region (Brown et al 2008). Furthermore, a thorough understanding of the distribution and presence patterns of molluscan species is essential for establishing taxonomic and biological connections between closely related taxa, as well as for the development of conservation and management strategies.

The research provided seminal findings regarding the diversity of mollusks in relation to lake profile data, including physicochemical properties. The study utilized Apo, Pinamaloy, and Napalit lakes located in the South Cotabato region of Mindanao, Lakewood, and Dasay lakes situated in Zamboanga del Sur, and Holon Lake located in the Bukidnon area. For the preservation and organization of taxonomy-related data, the inventory of these molluscan species is an indispensable resource (Batomalaque et al 2010). Given the lack of published research on mollusks in lakes, the baseline data obtained from this investigation would unquestionably prove beneficial for future science.

Material and Method

Description of the study sites. Geographically separated from one another, the study region consists of six distinct lakes in Mindanao, Philippines (Figure 1).

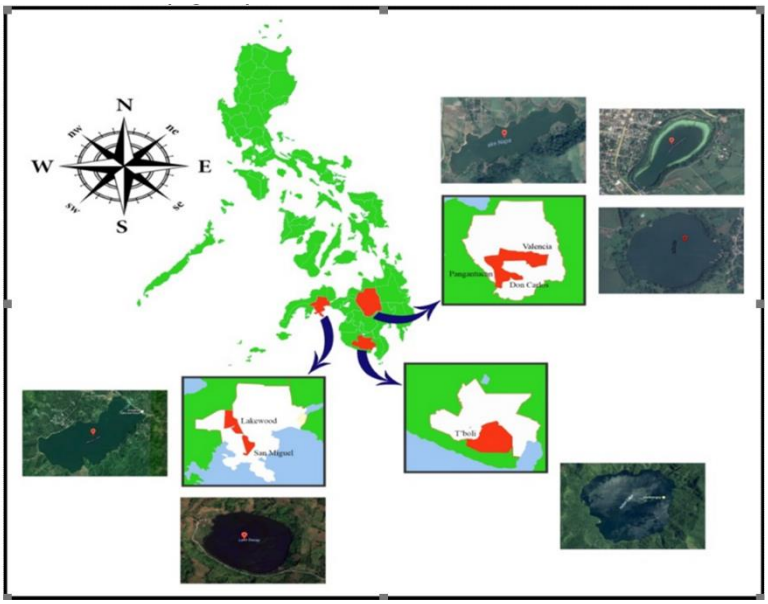

Figure 1. The location of six lakes in the island of Mindanao, Philippines.

Lake Apo is a lake located within the Bukidnon province (Figure 2A). It is located in the barangay of Guinoyoran in Valencia. Lake Pinamaloy, the second lake, is located in the municipality of Don Carlos in the Bukidnon region (Figure 2B). Lake Napalit, situated in Barangay Pigtauranan, Pangantucan, is the third lake in the province of Bukidnon (Figure

2C). It is located just outside the Kalatungan Mountain Range. Lake Lakewood is located in the municipality of Lakewood, which is situated in the eastern region of the central Zamboanga Peninsula. The towns of San Miguel and Lake Dasay, located in Zamboanga del Sur province in the Philippines, are home to the second-largest alpine lake in the province, known as Lake Lakewood (previously known as Lake Maughan). Another notable lake, Lake Holon (Figure 2F), is situated in T'Boli, South Cotabato. Table 1 provides an overview of the characteristics of the lakes in general.

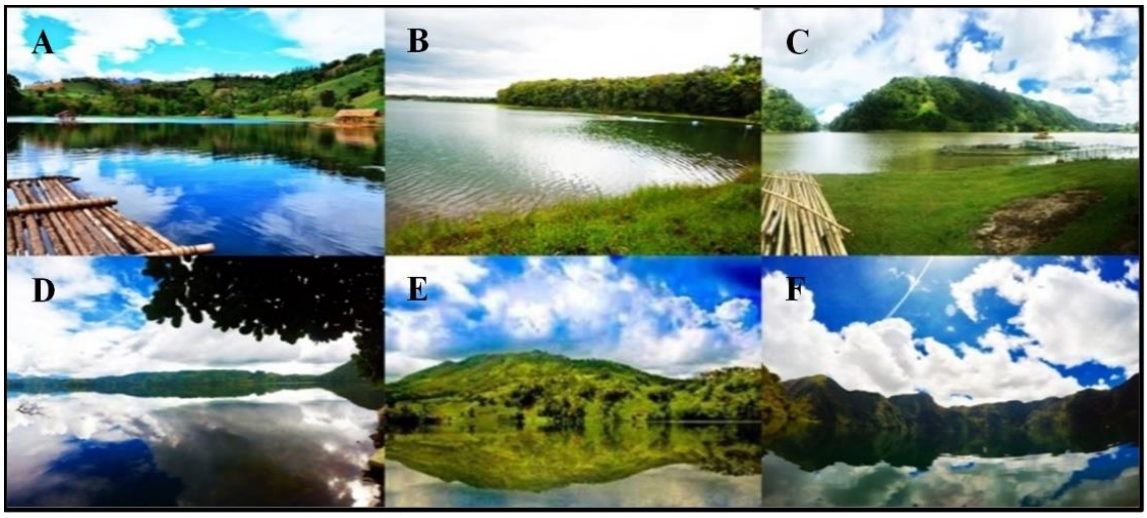

Figure 2. Actual images of (A) Lake Apo (B) Lake Pinamaloy, (C) Lake Napalit, (D) Lake Lakewood, (E) Lake Dasay, and (F) Lake Holon.

Table 1

Characteristics of the lakes

Lake	*Type*	*Substrate type*	*Surface area (ha)*	*Elevation (ft.)*	*Coordinates*
Apo	Crater	Medium and Fine	24	2,100	7°52′45″N 125°0′21″E
Pinamaloy	Tectonic	Medium and Fine	60	1,024	7°40′15″N 124°59′59″E
Napalit	Tectonic	Medium and Fine	35	3,415	7°52′5″N 124°47′3″E
Lakewood	Tectonic	Coarse, Medium and Fine	738	1,050	7°50′36″N 123°9′47″E
Dasay	-	Medium and Fine	40	750	7°39′43″N 123°15′11″E
Holon	Crater	Medium and Fine	317	1,338	6°6′5″N 124°53′20″E

Sample collection, processing, and identification. Opportunistic random sampling was conducted by means of netting, selecting, scooping, and diving. Although numerous variables may have influenced the occurrence of freshwater mollusks, the research was limited to a single sampling for water and mollusk species from the coastal regions. Following the samples' flesh removal, the shells underwent a cooking process in water prior to being rinsed with stream water. A representative sample was refrigerated and stored in 95% ethyl alcohol. The species' taxonomy was established by using specialist literature and a small number of mollusk catalogs that relied on morphological traits. The existence of a mollusk species in a certain lake is considered to indicate the whole range of biological conditions and resources available in that lake.

Secondary data and physico-chemical parameters. A compilation of secondary data was made from an assortment of online resources. Established standard procedures were employed to ascertain the physical and chemical properties. Early in the morning, between 7:00 a.m. and 11:00 a.m., all water samples were collected into 6-gallon polythene receptacles. In situ measurements of dissolved oxygen (DO), water temperature, and hydrogen potential (pH) were conducted utilizing a portable DO meter and refractometer, among other physicochemical parameters. The biochemical oxygen demand (BOD), total suspended solids (TSS), total dissolved solids (TDS), nitrate, reactive phosphate, and potassium were analyzed by F.A.S.T Laboratories in accordance with the standard procedures (Table 2). The Turkish Water Pollution Control Regulation (TWPCR 2008) was applied to categorize water quality.

Table 2

List of physicochemical parameters with their corresponding unit of measurement and method of analysis

Test	*Unit*	*Method*
BOD	mg L^{-1}	5210 B. Azide Modification
TSS	mg L^{-1}	2540 D. Gravimetry
TDS	mg L^{-1}	2540 C. Gravimetry
Nitrate	mg L^{-1}	973.50 Bruccine Colorimetric Method
Phosphate	mg L^{-1}	4500-P D. Stannous Chloride
Potassium	mg L^{-1}	3030 F. Nitric Acid Hydrochloric Acid Digestion, 3111 B. Direct Air-Acetylene Flame AES

Results and Discussion. A variety of environmental factors and characteristics may influence the presence or absence of mollusk species in the lakes. Alterations to physicochemical variables, whether induced directly or indirectly, affect the distribution of mollusk species in lakes (Lardicci et al 1997). Table 3 presents the average values of the physical and chemical parameters of Lake Apo, Napalit, Lakewood and Holon. Lake Dasay and Pinamaloy data were not collected due to the unavailability of equipment during the designated sampling dates. Additionally, bio-monitoring is omitted from the study due to the utilization of a solitary sampling technique.

Table 3

Mean values and laboratory outputs of the physical-chemical parameters in each lake

Parameters	*Apo*	*Napalit*	*Lakewood*	*Holon*
pH	7.5	7.8	4.73	-
Temp	26.13	23.63	29.6	25.36
DO	3.5	8.62	4.97	5.47
BOD (mg L^{-1})	2	4	2	1
TSS (mg L^{-1})	2	17	1	1
TDS (mg L^{-1})	42	33	78	31
Nitrate (mg L^{-1})	0.03	0.04	0.11	$<0.03^{b}$
Phosphate (mg L^{-1})	$<0.01^{b}$	$<0.01^{b}$	$<0.01^{b}$	$<0.01^{b}$
Potassium (mg L^{-1})	2.05	1.09	1.46	16.2

pH for Lake Holon was not recorded because the testers were unavailable.

A total of eight distinct species of mollusks were collected from six lakes situated in desolate regions of Bukidnon Province, Zamboanga Peninsula, and South Cotabato, all in the Philippines (Table 4, Figures 3-5). The Phylum Mollusca classified Bivalvia and Gastropoda as their two subclasses. These species belong to six families: Planorboidae, Unionidae, Viviparidae, Ampullariidae, Thiaridae, and Lymnaeidae. *Sinanondonta woodiana* was the only bivalve species identified; all other species were gastropods. Two species, namely *Tarebia granifera* and *Melanoides tuberculata*, were identified as members of the Thiaridae family. *Vivipara angularis*, one of these species, is indigenous to the Philippines;

the remaining six are believed to be introduced, or native invasive species, and an unidentified species completes the list. The species *Pomacea canaliculata* exhibited the highest prevalence followed by *S. woodiana* and *V. angularis*, respectively. Economically, only a few of the species are significant.

In contrast to *P. canaliculata*, which was considered an agricultural nuisance, *V. angularis* was the only species that was regularly collected and sold for human consumption. As vectors of zoonotic diseases, *S. woodiana*, *M. tuberculata*, *T. granifera*, *Radix natalensis*, and *Planorbis sp*. have been identified. As expected, these organisms induce ailments and disrupt the well-being of both fauna and humans.

Table 4

Checklist of mollusk species present in geographically isolated lakes

	Bukidnon Province			*Zamboanga Peninsula*		*South Cotabato*	*Status*	*Ecological and medicinal importance*
	Apo	*Pinamaloy*	*Napalit*	*Lake Wood*	*Dasay*	*Holon*		
Bivalve								
Sinanodonta woodiana	+	+	+	+	+	-	Introduced (Invasive)	Vector for zoonotic diseases
Gastropod								
Vivipara angularis	+	-	+	+	+	+	Native	Used as food; Known vector for zoonotic diseases
Pomacea canaliculata	+	+	+	+	-	+	Introduced (Invasive)	Agricultural pest
Melanoides tuberculata	+	-	-	+	-	+	Indigenous (Invasive)	Vector for zoonotic diseases
Tarebia granifera	+	-	-	+	-	+	Indigenous (Invasive)	Vector for zoonotic diseases
Radix natalensis	-	-	+	+	-	+	Introduced (Rare)	Vector for schistosomiasis
Planorbis sp.	+	-	-	+	-	-	Introduced	Vector for schistosomiasis
Bullastra sp.	+	-	+	-	-	-	Unknown	Unknown

The physicochemical parameters of the four lakes listed in Table 3 formed a number of significant associations with the presence of the mollusk species (Table 4). Significant variations were observed in all physicochemical parameters with the exception of phosphate (less than 0.01b), found in the natural concentrations indicating that algal colonies rarely contaminate the lakes. Lake Lakewood and Lake Napalit have basic (7.8 and 7.5) pH values, respectively, while Lake Lakewood is mildly acidic (4.73). Most species cannot persist in water that is either too basic (above 9.0) or too acidic (below 5.0), as their optimal pH range is between 7.0 and 9.0. In contrast, the mollusk species collected from Lake Apo and Lakewood exhibited a negligible and mild negative correlation with pH. The dissolved oxygen (DO) concentrations and temperatures of the four lakes (3.5–8.62 mg L^{-1} and 23.63–29.6°C, respectively) are typical for freshwater entities. A diminished DO indicates an unhealthy ecosystem. Nevertheless, the mollusks exhibit a negligible negative correlation with DO, as certain species can endure extremely low oxygen conditions; this suggests that these variables have an inverse relationship. A positive correlation was observed between water temperature and the presence of mollusk species, as evidenced in the Lake Lakewood (29.6°C), where an increase in temperature within the observed range promotes the growth and abundance of mollusks. *P. canaliculata* was detected in five out of six lakes due to its temperature-dependent activity rate; at temperatures as high as 25°C, it is capable of actively proliferating, surviving, and moving about. In contrast

to water temperature, DO exhibited a negligible negative correlation with the species present in a given lake. Biochemical oxygen demand (BOD) levels increase when DO levels are insufficient due to bacterial oxygen consumption in the water. Lake Holon (1 mg L^{-1}) has the lowest BOD, indicating pristine water, followed by Lake Apo, Lake Napalit, and Lakewood (4 mg L^{-1}), all of which have a moderate level of contamination. The results suggested a positive correlation between the biomass decomposition (BOD) and the diversity of mollusk species present in the lakes. Lake Holon and Lakewood exhibit the lowest concentrations of total suspended solids (TSS) at 1 mg L^{-1}; lakes Apo and Napalit follow at 2 mg L^{-1} and 17 mg L^{-1}, respectively. Due to the turbid water during the sample period, the total dissolved solids (TDS) concentration at Lake Lakewood is exceptionally high, 78 mg L^{-1}. Water is more contaminated or toxic when its TSS and TDS levels are more significant and it appears murkier. Despite the fact that Lake Lakewood (0.11 mg L^{-1}) contained the highest concentration of nitrate, which is necessary for the growth of the mollusks collected, the nitrate concentrations in all lakes remain within their natural ranges.

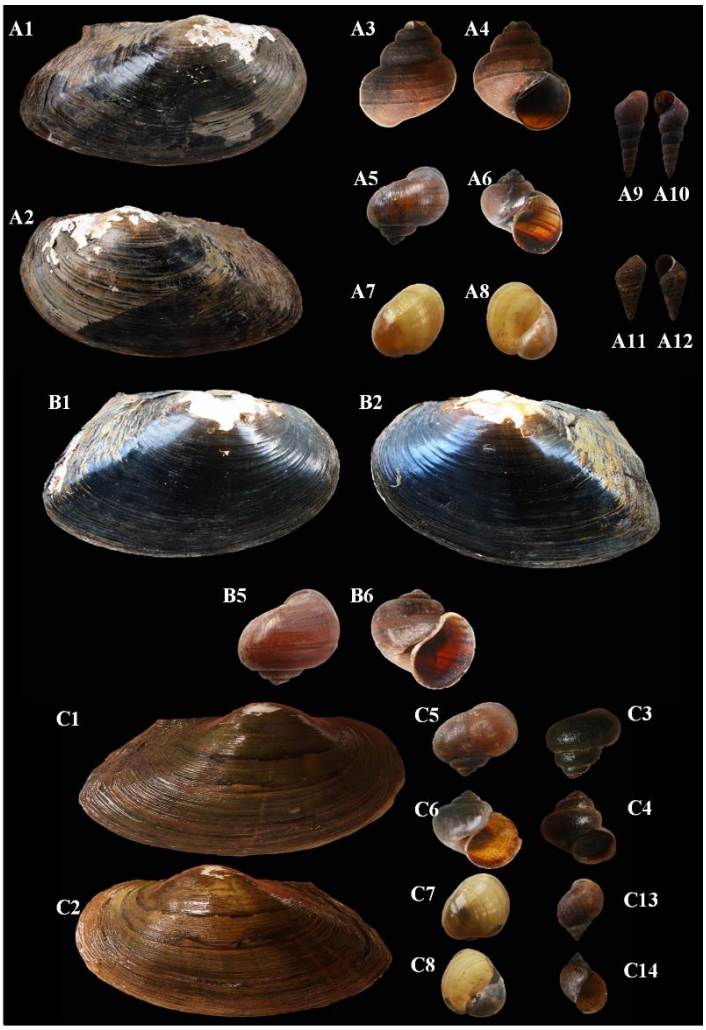

Figure 3. Representative species of mollusks collected in Lake (A) Apo, (B) Pinamaloy and (C) Napalit situated in the Bukidnon Province, Philippines. A, B and C (1R-2L): *Sinanondonta woodiana*, A and C (3D-4V): *Vivipara angularis*, A, B and C (5D-6V): *Pomacea canaliculata*, A and C (7D-8V): *Bullastra* sp., A (9D-10V): *Melanoides tuberculata*, A (11D-12V): *Tarebia granifera* and C (13D-14V): *Radix natalensis*. R-right, L-left, D-dorsal and V-ventral view.

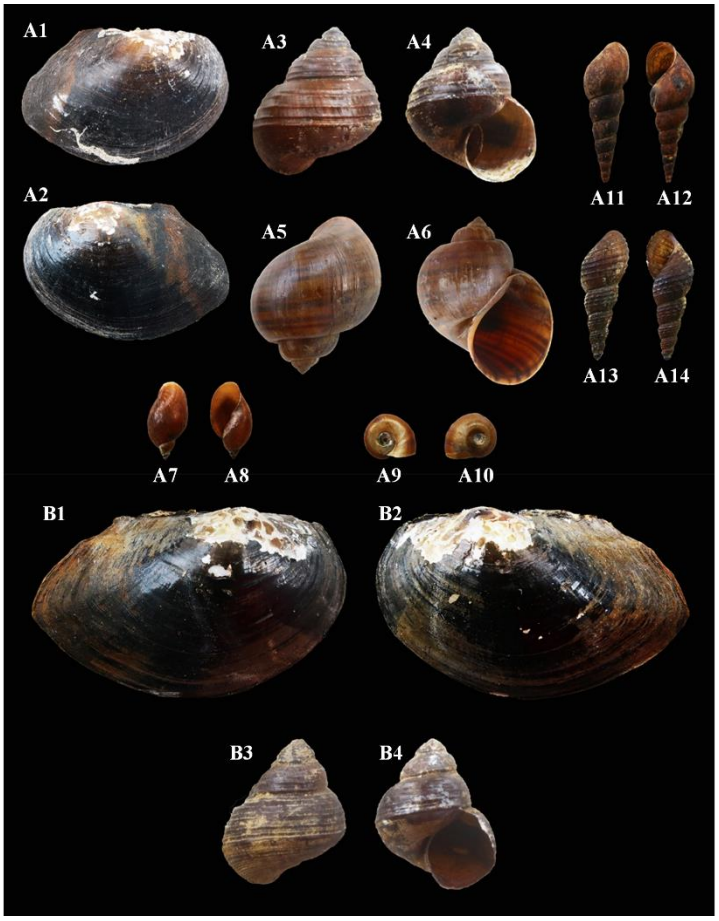

Figure 4. Representative species of mollusks collected in Lake (A) Lakewood and (B) Dasay situated in Zamboanga Peninsula, Philippines. A and B (1R-2L): *Sinanondonta woodiana*, A and B (3D-4V): *Vivipara angularis*, A (5D-6V): *Pomacea canaliculata*, A (7D-8V): *Radix natalensis*, A (9D-10V): *Planorbis* sp., A (11D-12V): *Melanoides tuberculata* and A (13D-14V): *Tarebia granifera*. R-right, L-left, D-dorsal and V-ventral view.

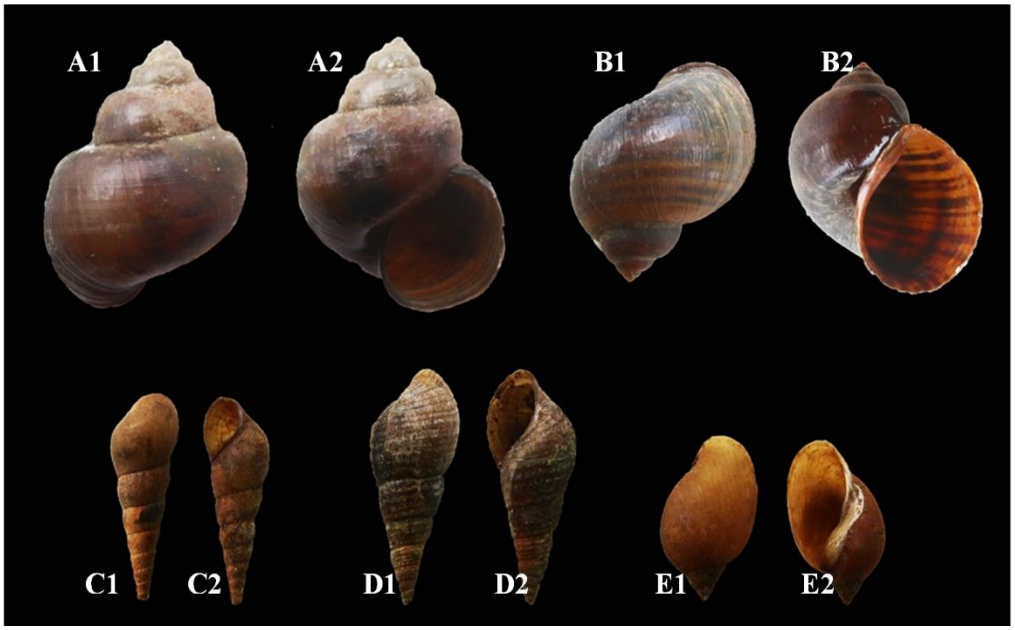

Figure 5. Representative species of mollusks collected in Lake Holon situated in South Cotabato, Philippines; (A) *Vivipara angularis*, (B) *Pomacea canaliculata*, (C) *Melanoides tuberculata*, (D) *Tarebia granifera.*

It was also demonstrated that nitrates, phosphates, and nutrients correlated favorably with the species of mollusks. No substantial impact on mollusk abundance was observed in response to variations in the values of these nutrients in the lakes. In summary, the lakes were classified into three distinct categories: mesotrophic (characterized by average nutrient levels and good clarity), eutrophic (beneficial to plant growth and nutrient enrichment but prone to algal blooms), and hypertrophic (destructive algal flowers and excessive nutrient enrichment, accompanied by poor clarity).

Furthermore, Lake Pinamaloy in the province of Bukidnon seems to be subjected to exploitation, evidenced by the presence of only two mollusk species. The lake has been utilized for recreational purposes, surrounded by human dwellings, and fed by local runoff. Consequently, the lake's grounds exhibit visible signs of trash. The unchecked growth of water lilies in the lake poses a significant issue, providing excessive cover that emits foul aromas, darkens the water entirely, and depletes oxygen at night. These factors collectively contribute to adverse effects on aquatic life, making it imperative to address the environmental challenges faced by Lake Pinamaloy.

Lake Lakewood in the Zamboanga Peninsula and Lake Apo in Bukidnon, on the other hand, stand out as the primary habitats for the majority of collected and identified mollusk species. Since the late 1990s, Lake Apo has been touted as the finest inland body of water in the Northern Mindanao region. Currently, a private merchant, responsible for its maintenance and conservation, owns and administers the majority of this tranquil lake. Despite the presence of human settlements in the vicinity and the influx of tourists, the lake remains an idyllic destination for a refreshing plunge. Across the entirety of the lake, one can anticipate a profusion of gastropods and an abundance of fish, despite being the smallest among all lakes. Meanwhile, Lake Lakewood is the most expansive among the lakes. It is encircled by numerous barangays inhabited by Subanen tribe members, retreats, and agricultural land. Scheiner (2003) and Tjørve (2003) published that there is a positive correlation between the expansion of a region and the number of species present. However, the method and the particularities of the area may influence the nature of the relationship between the number of species and the area's extent. Certain regions of the lake remain unexplored due to their vastness, the peril presented by untamed terrestrial and aquatic fauna, and the impossibility of accessing them via any mode of transportation (hiking is not recommended). Furthermore, observations indicate that the lake is surrounded by refuse, emits an offensive odor, contains discolored water, and is teeming with a wide variety of aquatic plant species. Notwithstanding these circumstances, a profusion of fish and mollusk species thrives in that area, including carp and porang, both in significant numbers and sizes.

Five distinct species of gastropods have been identified in Lake Holon in South Cotabato. It is widely recognized as a cherished gem of Mindanao, boasting an abundance of species and pristine waterways. This lake holds significant cultural importance, being considered a sacred landmark by the Tboli tribe. Access to this secluded region is limited to those willing to embark on strenuous equestrian riding and trekking. Visitors seeking excitement are permitted to enter and exit the lake, provided they adhere to regulations implemented to safeguard the lake from pollution and hazardous substances. Meanwhile, the Lake Napalit, with 5 identified mollusk species, is utilized by the locals it for bathing and as a natural laundromat. These activities exemplify anthropogenic disturbances. Similar to Lake Holon, the lake possesses profound spiritual and mystical importance within the Manuvu tribe. Various fish species, such as carp, tilapia, and gurami, inhabit the lake. It is surrounded by agricultural land. Species of mollusks are uncommon and challenging to locate in the lake.

Generally, diversity of both bivalves and gastropods displayed a significant variation in the selected lakes. Certain species dominate exclusively due to habitat degradation, anthropogenic intrusions, species coexistence, and the lake characteristics. Despite its comprehensiveness, a survey limited to a single season may not adequately capture a species because some organisms exist exclusively during specific seasons or intermittently.

According to Bhattacherjee (2008), the presence of a varied benthic fauna population signifies that the water quality is satisfactory for their sustained existence within the ecosystem. Strzelec & Krolczyk (2004) also stated that numerous mollusk species

exhibit tolerance towards diverse physicochemical parameters due to the abundance of flora and the caliber of the substrate. Conversely, inadequate food quality in semipermanent habitats may inhibit the formation of mollusk communities, as stated by Jurkiewicz-Karnkowska (2011). Also significantly influenced by physical changes are variations in the abundance of mollusks in space. Browne (1981) and Pip (1986) found that the composition of gastropod communities in lakes in close proximity to one another can vary considerably. This is not the situation with the lakes in Zamboanga and Bukidnon, where numerous species are frequently observed. According to Gupta and Bhagat (2005), the effects of pollution and eutrophication may be readily apparent in these species, as they are vulnerable and spend the majority of their lives in a single location due to their notoriously limited mobility.

Srivastava & Jauhari (1990) examined the freshwater gastropod *M. tuberculata*, discovering that population fluctuations correlated with various abiotic factors. The results of their investigation substantiated these conclusions, suggesting that altered lake habitats and potential life-threatening stress on mollusk species could be attributed to climate change as an abiotic factor. An exploration of the population dynamics and distribution of freshwater snails in recently inhabited regions of the Sinai Peninsula revealed distinct variations in the presence of these snails across various habitats, as well as in the bionomics of aquatic snails. Researches conducted by Gupta et al (1987) and El-kady et al (2000) supported the findings of the present investigation, which focused on population variation between geographically distinct lakes. Additionally, Gupta & Khajuria (2004) conducted a study on the ecology of freshwater snails in Lake Mansard, Jammu. Their research unveiled variations in the correlation coefficient between physicochemical parameters and the species of gastropods inhabiting the littoral, sublittoral, and profundal zones of the lake. While the present investigation solely focused on the littoral zone, further research is necessary to generate comprehensive results. Lastly, Singh & Panwar (1998) proposed that the bionomics of a limited number of Merruti water snail species caused significant seasonal variation among the snail species. However, the present study differs from the previous investigation due to its exclusive reliance on a one-time sampling procedure. To mitigate biases, future biomonitoring research should be conducted in the selected lakes, requiring several months of sampling and observation.

Conclusions. The current study represents the initial account of the bivalve and gastropod fauna in the chosen lakes. Mollusks have been classified into six families, seven genera, and eight species. Three invasive species were present among these mollusks. Additionally, it can be deduced that most of the water's physicochemical characteristics are crucial for the development and survival of the mollusk population in lakes. According to a preliminary analysis, Lake Holon has crystal-clear waters, but Lake Apo and Lakewood have moderate pollution levels. The study serves as a benchmark reference for mollusk research, particularly on habitat preferences and how these species play a significant role as biological indicators for environmental and anthropogenic stresses and climate change experienced by the lakes. This will help experts establish conservation management strategies to preserve endemic biodiversity and sustain ecologically important species.

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Conflict of interest. The authors declare no conflict of interest.

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Authors:
Christine Lovelle Mahinay-Cardente, Biology Department, Xavier University-Ateneo de Cagayan, Cagayan de Oro City, 9000, Philippines, e-mail: lovelle2200@gmail.com
Mark Anthony Jariol Torres, Center of Integrative Health/Climate Change Laboratory, Premier Research Institute of Science (PRISM), Department of Biological Sciences, and School of Interdisciplinary Studies, MSU-Iligan Institute of Technology, Tibanga Iligan City, Philippines, e-mail: tores.markanthony@g.msuiit.edu.ph
Cesar Guinanao Demayo, Center of Integrative Health/Climate Change Laboratory, Premier Research Institute of Science (PRISM), and Department of Biological Sciences, MSU-Iligan Institute of Technology, Tibanga Iligan City, Philippines, e-mail: cesar.demayo@g.msuiit.edu.ph
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