Freshwater and Land Mollusk Diversity Patterns Along Dakil River at the University of the Philippines Laguna Land Grant (UPLLG), Paete, Laguna, Luzon Island, Philippines

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ABSTRACT

Prior to this study, there had been no malacofaunal study in the University of the Philippines Laguna Land Grant (UPLLG). To address this, a diversity survey of its freshwater and land mollusks was conducted. A total of 25 quadrats (15 m2) on upstream and downstream stations along Dakil River and its tributaries for freshwater mollusks and 12 quadrats (100 m2) for land snails were set randomly to correlate their diversity patterns with environmental variables. From 115 individuals of freshwater mollusks, seven species (six gastropods, one bivalve) belonging to six families (Ampullariidae, Corbiculidae, Lymnaeidae, Neritinidae, Thiaridae, and Viviparidae) were identified. On the other hand, seven species belonging to three families (Ariophantidae, Camaenidae, and Chronidae) were identified among 28 land snail individuals. Malacofaunal survey revealed that the area along Dakil River has low diversity in both freshwater mollusk (H'=1.40) and land snail (H'=1.19). Generalized linear mixed models (GLMM) revealed river velocity was the most significant predictor for species richness of freshwater mollusks, and abundance was highly affected by temperature and inversely affected by canopy cover. Furthermore, altitude was the most significant predictor for species richness of land snails and canopy cover for abundance. Understanding the molluscan diversity could help determine the environment and ecological conditions of the watershed for its effective management and conservation.

Keywords: Diversity, freshwater mollusks, land snails, Dakil River, species richness, abundance

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INTRODUCTION

Mollusks have a significant role in the ecosystem by being key prey items, active detritivores, and efficient calcium recyclers. Mollusks such as gastropods and bivalves are also good habitat indicators because they can be found in areas with good habitat quality. However, one of the factors in the decline in their diversity and abundance are anthropogenic activities resulting in habitat destruction and modification. Riparian forests along tropical streams are one of the important ecosystems for the targeted conservation of mollusks (Clements et al. 2006); however, very few studies have examined mollusk communities in the forests along such waterways. In the Philippines, Flores and Zafaralla (2012) found water quality deterioration of Mananga River in Cebu based on physicochemical analyses. This deterioration was validated by low diversity index. With the extensive destruction and disturbance of freshwater and tropical forest ecosystems, there is a need for studies on malacofaunal biodiversity to provide useful and realistic data for conservation and management (Pérez-Quintero 2007).

One of the ideal sites for malacofaunal study is the watershed streams of the University of the Philippines Laguna Land Grant (UPLLG) in Paete, Laguna. It is a naturally grown secondary forest between Pakil and Paete. In 2001, UPLLG was included as an Important Biodiversity Area (IBA) as well as Key Conservation Site in the Philippines since many threatened and restricted-range birds among the Luzon endemics have been recorded in the area (Mallari et al. 2001; BirdLife International, 2016). UPLLG serves as a habitat for various lowland rat species, civets, and fruit bats, and supports heavily hunted large mammals such as the Philippine warty pig (*Sus philippensis*) and long-tailed macaque (*Macaca fascicularis*). The threatened endemic Gray's monitor lizard (*Varanus olivaceus*) is also known to occur in the area (BirdLife International 2016).

Prior to this study, there had been no study on the diversity of freshwater and land mollusks in the watershed streams of UPLLG. Understanding the molluscan diversity could help determine the environment and ecological conditions within this watershed for its effective management and conservation. Thus, this study aimed to 1) determine the diversity of freshwater and land mollusks in the watershed streams of Dakil River in UPLLG; 2) correlate the species richness and abundance with selected environmental variables; and 3) quantify the effect of each environmental variable on molluscan species richness and abundance.

MATERIALS AND METHODS

Study site

The University of the Philippines Laguna Land Grant (14° 23' N, 121° 29' E), formerly known as Paete Land Reservation, is a 3,435.4 ha land area that has been owned by the University of the Philippines since 1964. It is located across the municipalities of Paete, Pakil, and Kalayaan in the Province of Laguna and partly in Real, Quezon Province (Figure 1). It is a mountainous area with an elevation of 300 to 400 masl and is considered a part of the Sierra Madre Mountain Range. Historically, the area was exploited by slash-and-burn farming and logging that started in the 1920s and was severely logged in the 1960s, mostly on the outlying areas of Balian and Saray in Pakil, Laguna (Gonzalez 1995). In the mid-1990s, there was still evidence of illegal logging in the area, specifically that trees with a diameter of less than 50 cm were being cut. At present, UPLLG has mostly disturbed secondary growth lowland dipterocarp forests that include certain areas of permanent agriculture

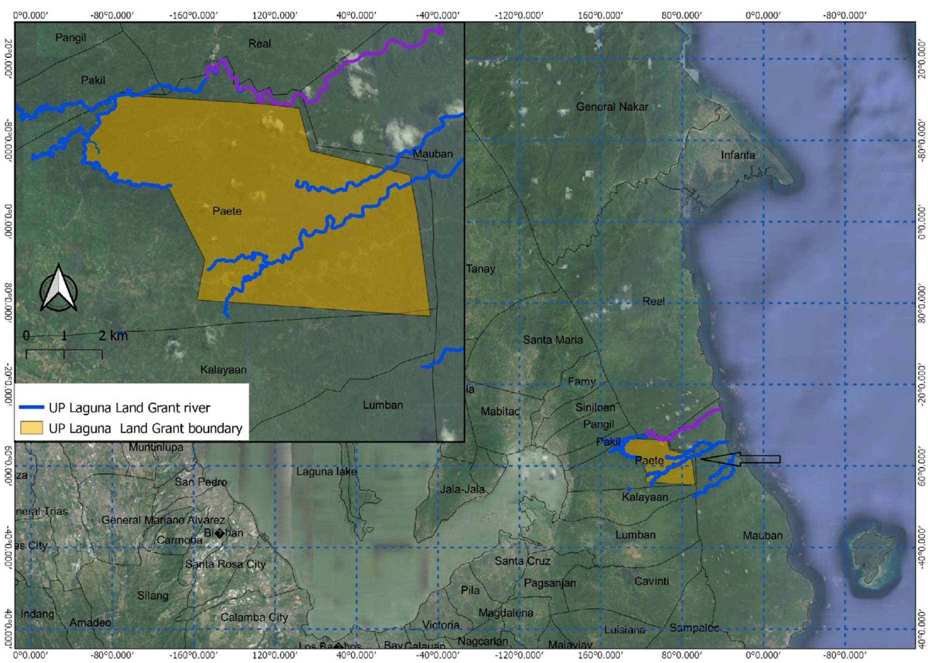

Figure 1. Location of the study site in the University of the Philippines Laguna Land Grant, Paete, Laguna, Philippines. (Map Source: Google Earth Satellite Image using QGIS version 3.4 Madeira).

(including rice paddies), *kaingin*, plantations, small settlements, and rural gardens (BirdLife International 2016). It is not considered a protected area but it is managed and protected through the efforts of the Laguna Land Grant Management Office of the University of the Philippines Los Baños. UPLLG has a total land cover of 3,435.4 ha with four major rivers running through it, namely Dakil, Tibag, Papatahan, and Ginabihan, all of which drain towards Lamon Bay in Quezon Province. The Dakil River has the largest watershed area, covering 2,989 ha with four tributaries draining to the main river.

Sampling protocol

The sampling method for freshwater mollusks used in this study was adapted from the method of Clements (2006). There were four tributaries present in the area, namely upstream 1 (UP1), upstream 2 (UP2), downstream 1 (DW1), and downstream 2 (DW2), and the main river (MR). Both the tributaries and the main river were sampled. In each of these locations, five 3 x 5 meter (15 m^2) quadrats were set at least 10 meters apart to prevent pseudoreplication. Overall, a total of 25 quadrats were established for the whole study. Physicochemical parameters were measured in each quadrat simultaneously with the freshwater mollusk sampling. Water temperature, pH, and conductivity were measured in situ using a multiparameter water quality meter (Oakton 35425-00, USA). At least three readings were measured at each sampling site. The average water current velocity was also measured using the floatation method (Singh 2003; Dobriyal et al. 2016) with five readings taken at each sampling site at equally spaced distances along the quadrat and then averaged. The substrate type was determined as gravel, pebbles, sand, and mud. Moreover, 1 L of sediments per plot was collected for cascade sieving using 3 mm, 2 mm, and 1 mm steel meshes. Samples were all fixed in 95% ethanol.

The land snail sampling method used in this study was adapted from the method of de Chavez and de Lara (2011). A total of twelve 10 by 10 meter (100 m^2) quadrats were randomly selected along the Dakil River. The sampling sites were at least 10 meters apart to prevent pseudoreplication. The air temperature was measured by a digital thermometer (Uni-T, Model UT333, China). The number of trees and their diameter at 1.3 m from the base was determined using a tape measure. Leaf litter depth was measured using a ruler placed vertically in the forest floor in the middle point and all the four corners of each quadrat. At least 1 L of topsoil was collected per quadrat. Soil pH was also measured (Milwaukee pH Tester, USA).

All geographic coordinates and elevation were determined using a Garmin® GPS 12 Personal Navigator® (Garmin International, Inc., USA). Percent canopy cover was measured using a concave spherical densiometer (Forest Suppliers, Inc., USA). Direct hand-search of freshwater mollusks and land snails with a two-hour sampling effort was allotted in each quadrat (de Chavez 2014). Both freshwater mollusks and land snails were identified to the species level using published literature such as Faustino (1930), Bartsch (1932), Springsteen and Leobrera (1986), and Abbott (1989). The sampling was done during the rainy season of October 2016. Identified specimens were deposited as vouchers to the University of the Philippines Los Baños Museum of Natural History.

Statistical Analyses

The individual count (relative abundance) and the total number of species per site (species richness) were determined for both freshwater mollusks and land snails. Standard diversity indices (Shannon-Weiner and Evenness) were also calculated using the software Paleontological Statistics (PAST) version 3.15 (Hammer et al. 2001).

In addition, an information-theoretic technique through model averaging (Grueber et al. 2011) was conducted to determine the corresponding effects of environmental variables measured on the species richness and abundance of freshwater mollusks and land snails along Dakil River. A generalized linear mixed-effect model (GLMM) was implemented using the *lme4* and *MuMIn* packages that were installed in R statistical software version 3.3.2. (R Development Core Team, Vienna, Austria). In defining model parameters, the number of species and abundance were coded as response variables while environmental variables were identified as fixed factors. Sampling sites were identified as the random variable. After running the codes, Akaike's information criterion corrected for small sample size (AIC_c) appeared. This was used to assess model support, ranking each set using ΔAIC_c (Burnham and Anderson 2002). The most parsimonious models were selected based on the largest Akaike information criterion corrected for small sample size by extracting the top five AIC_c.

RESULTS

Environmental variables

Water temperature throughout the stations was relatively uniform (24°C) while water pH was slightly acidic with a range of 5.08–6.37. However, this will vary across different seasons of the year. The sampling was conducted during the rainy season. Fast water velocities were recorded in UP2 station and DW2 station with a velocity of 6.54±0.16 m/s and 7.07±0.71 m/s, respectively. Among all the stations, the DW2 and MR stations were found to have the deepest water with 30.68±6.32 cm and 49.0±0.58 cm, respectively. DW1 has the highest canopy cover among all the stations at 76% (Table 1).

Table 1. Summary of physicochemical parameters of the upstream and downstream stations of Dakil River and its tributaries, UP Laguna Land Grant (UPLLG)

Environmental Variables	UP1	UP2	DW1	DW2	MR
Temperature (°C)	24.54 ±0.02	24.1 ±0.00	24.0 ±0.00	24.23 ±0.12	24.7 ±0.38
pH	5.08 ±0.28	6.37 ±0.10	6.09 ±0.17	6.20 ±0.30	6.37 ±0.38
Conductivity (µS/cm)	22.39 ±0.12	25.14 ±0.12	29.7 ±0.43	32.17 ±0.86	23.47 ±0.68
Velocity (m/s)	8.51 ±0.91	6.54 ±0.16	10.17 ±1.89	7.07 ± 0.71	10.87 ±0.81
Water depth (cm)	18.2 ±0.36	14.9 ±1.16	14.30 ±1.74	30.68 ±6.32	49.0 ±0.58
Canopy cover (%)	37.0 ±6.24	61.0 ±8.72	76.0 ±7.31	60.0 ±10.61	0
*Substrate type	C, S, P	C, S, P	C, S, M	C, S, M	M

*M=Mud, S= Sand, P=Pebble, C=Cobble

The sampling sites along the Dakil River were characterized by altitudes between 252 to 387 masl with extensive canopy cover (50–70%) except for sampling site 1 (25%). Air temperature ranged from 24 to 26°C. The soil was slightly acidic in nature with a pH range of 5.00 to 6.00. Moreover, a few trees (<30) with relatively small diameters (<90 cm) were present in all the sampling sites (Table 2).

Table 2. Summary of the environmental variables measured in all 100 m^2 sampling sites along Dakil River in UP Laguna Land Grant (UPLLG)

Environmental Variables	1	2	3	4	5	6	7	8	9	10	11	12
Altitude (masl)	365	369	354	350	353	252	335	344	349	387	372	335
Temperature (°C)	25	26	26	25	26	26	24	24	24	25	25	25
Canopy cover (%)	25	50	50	50	50	75	75	50	50	50	50	75
Number of trees	16	26	18	12	14	22	11	18	17	18	18	13
Soil pH	6	5	5.67 ±0.33	6	6	5	5.33 ±0.33	5.33 ±0.33	5	5.33 ±0.33	5.33 ±0.33	5.33 ±0.33
Leaf litter depth (cm)	5.18 ±1.12	6.64 ±1.32	3.48 ±0.87	4.74 ±0.88	8.40 ±0.73	6.90 ±0.60	5.32 ±1.05	7.66 ±1.19	1.62 ±0.45	4.04 ±1.37	4.58 ±1.43	2.82 ±1.16
Tree diameter (cm)	36.40 ±4.11	31.70 ±3.12	44.40 ±4.34	43.30 ±5.11	33.60 ±4.56	36.10 ±3.96	53.70 ±9.31	48.20 ±10.35	27.80 ±6.41	38.20 ±6.73	42.60 ±7.11	32.60 ±6.57

Freshwater and land malacofaunal diversity

For freshwater mollusk diversity, a total of 115 individuals belonging to seven species (six gastropods and one bivalve) were recorded (Figure 2). The prosobranch gastropod species belong to family Thiaridae, which is represented by *Stenomelania macilenta* (Menke 1830) and *Melanoides tuberculata* (Müller 1774); family Neritinidae represented by *Neritina* sp.; family Viviparidae represented by *Sinotaia angularis* (Müller 1774); and family Ampullariidae represented by *Pomacea canaliculata* (Lamarck 1822). Lymnaeidae represented by *Radix quadrasi* (Möllendorff 1898) was the only pulmonate observed at the site. *Corbicula fluminea* (Müller 1774) was the only bivalve representative. For land snail diversity, a total of 28 individuals belonging to seven species were recorded. These were *Macrochlamys* sp. from family Ariophantidae; *Calocochlea chrysocheila* (Sowerby I 1841), *Dryocochlias metaformis* (Férussac 1821) and *Helicostyla rufogaster* (Lesson 1832) from family Camaenidae; and *Hemitrichiella setigera* (Sowerby I 1841), *Hemiglypta* sp. and *Ryssota otaheitana* (Ferussac 1820) from family Chronidae (Figures 2 and 3).

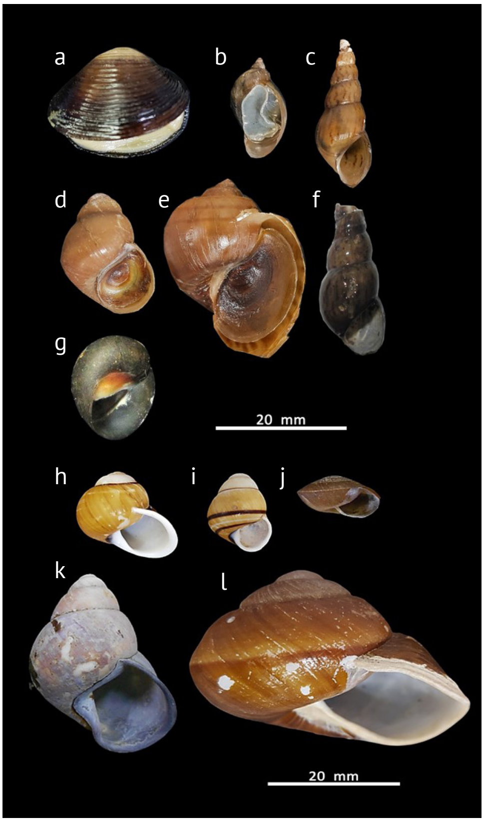

Figure 2. Diversity of freshwater mollusks (a to g) and land snails (h to l) along Dakil River, UPLLG: a. *Corbicula fluminea*; b. *Radix quadrasi*; c. *Melanoides tuberculata*; d. *Sinotaia angularis*; e. *Pomacea canaliculata*; f. *Stenomelania macilenta*; g. *Neritina* sp.; h. *Calocochlea chrysocheila*; i. *Dryocochlias metaformis*; j. *Hemiglypta* sp.; k. *Helicostyla rufogaster*; and l. *Ryssota otaheitana*.

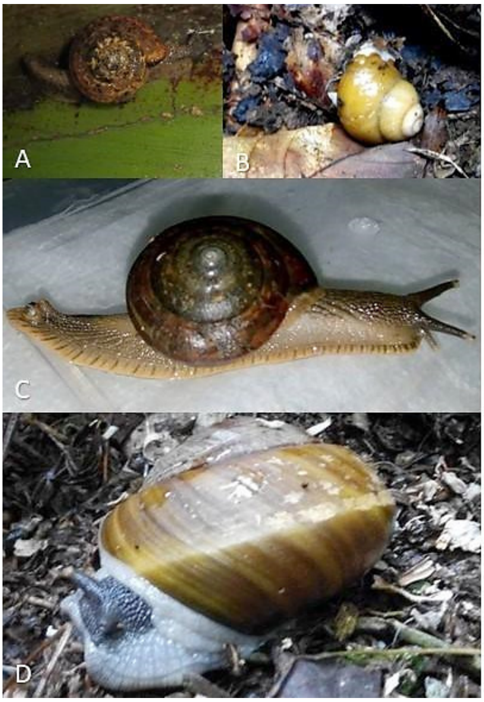

Figure 3. Live land snails found along Dakil River in UPLLG: A. *Macrochlamys* sp. found on a banana plant trunk; B. *Dryocochlias metaformis* on the moist leaf litters of the forest floor; C. *Hemitrichiella setigera* seen near the river; and D. *Ryssota otaheitana* present near roots of trees.

As for the overall malacofaunal diversity along the Dakil River in UPLLG, 14 species of freshwater mollusks and land snails were recorded. Freshwater mollusks were more abundant (115 individuals) than land snails (28 individuals), but both groups had similarly low diversity indices (H') at 1.40 and 1.19, respectively. Moreover, freshwater mollusks have an evenness value of 0.58 while land snails have 0.47 (Table 3).

Table 3. Summary of freshwater and land malacofaunal diversity in UPLLG

Parameters	Freshwater Mollusks	Land Snails
Total Species Richness	7	7
Total number of family	6	3
Total abundance	115	28
Shannon-Wiener (H')	1.40	1.19
Evenness (E)	0.58	0.47

The relationship among freshwater mollusks, sampling sites, and environmental variables is shown in the canonical correspondence analysis (CCA) biplot (Figure 4a). Results showed that the closer the variables to the snail species, the stronger the dependence or association of that species to specific environmental variables. Unrestricted Monte Carlo test for CCA 1 and CCA 2 was not significant at $p = 0.48$ and $p = 0.35$, respectively. The first two CCA axes accounted for 51.70% and 27.69% variation in the taxon composition. The biplot shows that *Pomacea canaliculata* and *Sinotaia angularis* are related to depth and temperature. The bivalve, *Corbicula fluminea*, was inversely correlated to fast current with slightly acidic water while *Melanoides tuberculata*, *Radix quadrasi*, and *Stenomelania macilenta* were associated with low conductivity. *Neritina* sp. was not related with any of the environmental variables measured since it was only found in a single site; therefore, it could not account for a direct relationship.

On the other hand, the relationship among land snail species, sampling sites, and environmental variables along Dakil River in UPLLG was shown using the CCA biplot in Figure 4b. The continuous environmental variables (altitude, temperature, canopy cover, soil pH, number of trees, diameter of tree trunks, and leaf litter depth) were represented as vectors while the nominal variable, sampling sites, was marked as black spheroids. Land snail species were designated as blue spheroids. The dominant variables found were altitude, soil pH, and the number of trees. Unrestricted Monte Carlo test for CCA 1 and CCA 2 was not significant at $p = 0.14$ and $p = 0.72$, respectively. The first two CCA axes accounted for 49.35% and 29.20% variation in the taxon composition. It can also be seen in the

CCA biplot that most of the land snail assemblage is in an area opposite to the direction of the altitude and soil pH. *Ryssota otaheitana* was closer to altitude and soil pH compared to other snail species. Among the seven species, *Macrochlamys* sp. was not directly affected by the existing conditions in secondary forests since it was found only in a single site; thus, it is not directly related to the environmental variables measured.

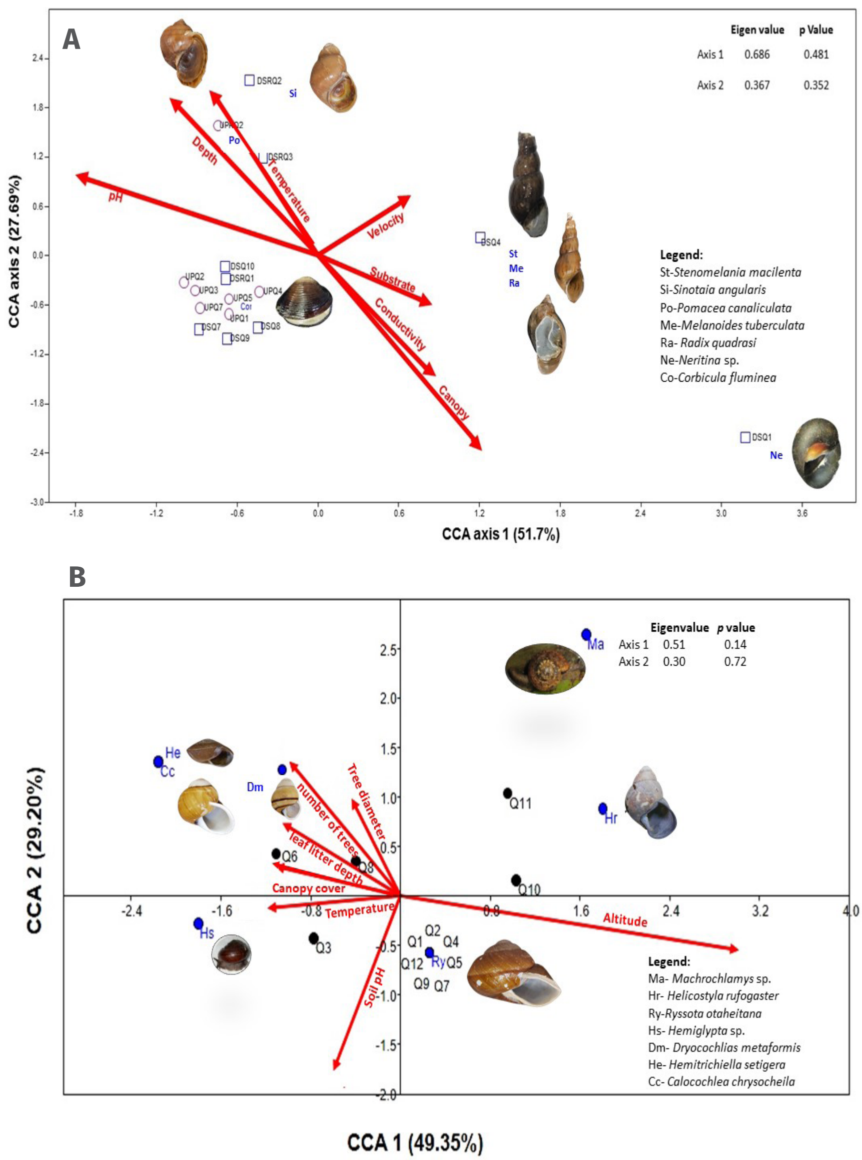

Figure 4. Canonical correspondence analysis (CCA) showing the relationship of freshwater mollusks (A) and land snails (B) against selected environmental variables and sampling sites.

After running the GLMM in a global model, the standardized parameter estimates revealed that river velocity is the most significant predictor in determining the species richness (E = 0.1769, $p<0.05$) of freshwater snails along the Dakil River in UPLLG (Table 4a). In general, the estimated values showed a positive relationship between the response variables and the quadrats, i.e. more species and more numerous individuals will be expected in slow water velocity. In case of abundance, additional factors were influential such canopy cover (E = -0.0145, $p<0.001$) and temperature (E = 0.9621, $p<0.001$) (Table 4a). Moreover, since the parameter estimate values were relatively close to each other, model averaging was implemented to generate sub-models to explain more clearly the variables by considering the top two AIC_c. River velocity is revealed to be the most significant predictor (ΔAIC_c = 0.0, $wAIC_c$ = 0.35) for species richness while null (ΔAIC_c = 0.0, $wAIC_c$ = 0.39) or none of the mentioned environmental variables influences abundance.

In addition, the standardized parameter estimates revealed that altitude is the most significant predictor in determining the species richness (E = -0.0106, $p<0.10$) of land snails along Dakil River in UPLLG (Table 4a). In general, the estimated values showed an inverse relationship between the response variable and altitude, i.e. more species and more numerous individuals will be expected in the lowest altitude. In the case of abundance, canopy cover was also influential (E= 0.0286, $p < 0.10$) Table 4a. Moreover, since the parameter estimate values were relatively close to each other, model averaging was implemented to generate sub-models to explain more clearly the response variables by considering the top two AIC_c. For species richness, altitude (ΔAIC_c = 0.00, $wAIC_c$ = 0.24) and null (ΔAIC_c = 0.03, $wAIC_c$ = 0.24) were the most parsimonious model; for abundance (ΔAIC_c = 0.00, $wAIC_c$ = 0.19), the most parsimonious model was canopy cover. Null means none of the mentioned environmental variables influence species richness (Table 4b).

Table 4a. Generalized linear mixed models of each environmental variable on their corresponding effect on species richness and abundance of freshwater mollusks and land snails along Dakil River in UP Laguna Land Grant, Paete, Laguna

Parameter	Estimate$^{\delta}$	SE	*P*	Relative Importance
Species richness				
Intercept$^{\Psi}$	-0.2055	6.3683	0.9758	
River velocity$^{\Psi}$	0.1769	0.0800	0.0476*	0.60
Water pH$^{\Psi}$	-1.1401	0.8085	0.2026	0.22
Temperature$^{\Psi}$	0.4690	0.5795	0.4558	0.12
Intercept$^{\Phi}$	1.2833	4.0214	0.7681	

Parameter	Estimate[δ]	SE	*P*	Relative Importance
Altitude[ϕ]	-0.0106	0.0055	0.0954*	0.40
Number of trees[ϕ]	0.0646	0.0531	0.2934	0.13
Canopy cover[ϕ]	0.0111	0.0208	0.6337	0.09
Abundance				
Intercept[Ψ]	-0.8982	8.3421	0.9149	
Canopy cover[Ψ]	-0.0145	0.0038	0.00059***	0.16
Temperature[Ψ]	0.9621	0.0038	< 2e-16***	0.13
Depth[Ψ]	0.0146	0.0179	0.4637	0.09
Intercept[ϕ]	1.7709	3.9034	0.6726	
Canopy cover[ϕ]	0.0286	0.0148	0.0955***	0.35
Altitude[ϕ]	-0.0097	0.0050	0.0894	0.33
Soil pH[ϕ]	-0.7715	0.5322	0.2084	0.19

[Ψ]Freshwater mollusks
[ϕ]Land snails
[δ]Effect sizes have been standardized on two SD following Gelman (2008)
*(P < 0.05)
***(P < 0.001)

Table 4b. Summary statistics of model averaging for species richness and abundance of freshwater mollusks and land snails. Models are ranked based on Akaike's information criterion corrected for small size (AIC_c)

Component Models	*k**	AIC_c	ΔAIC_c	$wAIC_c$
Species richness				
River velocity[Ψ]	5	55.84	0.00	0.35
Null[Ψ]	3	57.35	1.51	0.10
Altitude[ϕ]	3	39.99	0.00	0.24
Null[ϕ]	2	40.02	0.03	0.24
Abundance				
Null[Ψ]	3	102.82	0.00	0.39
Canopy cover[Ψ]	4	104.59	1.77	0.16
Canopy cover[ϕ]	3	47.52	0.00	0.19
Altitude[ϕ]	3	47.70	0.19	0.17

[Ψ]Freshwater mollusks
[ϕ]Land snails
**k* = number of parameters

DISCUSSION

Freshwater mollusks found in Dakil River in UP Laguna Land Grant showed specific habitat preference. The community distribution might be affected by environmental factors operating at a more local scale instead of global factors operating on a larger scale such as latitude and temperature. In this study, freshwater mollusks were observed to be independent of the site but dependent on their specific microhabitat in the sites. The presence of diverse microhabitats in the heterogeneous environment may favor the existence of six species of gastropods and one species of bivalve, as it allows species to avoid competition (Pointier 1993). In the study of Liongson et al. (2005), temperature and rainfall vary with altitude, thus affecting the microhabitat of freshwater mollusks in Mt. Makiling. However, this study did not include altitude as an environmental variable for freshwater mollusks.

The overall Shannon-Weiner in this study was relatively low (H' = 1.40). According to Magurran (2004), the diversity index in a natural ecosystem ranges from 1.5 to 3.5 where a value above 3.0 indicates a stable habitat while under 1.0 indicates a highly disturbed environment. Moreover, Flores and Zafaralla (2012) stated that a diversity index lesser than 2.5 is relatively low, thus mollusk diversity in this study has a low diversity index. However, this low diversity index value of the sampling sites would be significant if the sampling was done for a longer period of time and seasonality, noting that in this present work the sampling was done for only three days. Species richness varied significantly while the opposite was true for abundance against the river velocity, which selectively favored some species of freshwater snails. In the tributaries of Dakil River, juvenile *Corbicula fluminea* was frequently found. This could be attributed to its reproduction capabilities since this species is a simultaneous hermaphrodite, capable of crossing and self-fertilization (McMahon 1982). In addition, a flexible feeding strategy may enhance the success of *C. fluminea* when phytoplankton resources are scarce. This species can deposit feed on organic matter on sediments (Palmer 1999 as cited by Freedman 2013). During deposit feeding, *C. fluminea* uses cilia on its foot to collect organic matter from the surface of sediments or interstitially while burrowing (Reid et al. 1992 as cited by Freedman 2013).

For land snails, *Ryssota otaheitana* is the most abundant and widespread species. Because of its large size, which can reach up to 85 mm in shell diameter, this species can be easily seen during sampling (mostly at the base of buttresses) compared to other snails (de Chavez and de Lara 2011). It has discoidal and thick shells with a chestnut brown color in its spire and base (Bartsch 1938 as cited by de Chavez and de Lara 2011). Its abundance is an indication that this species is the most ecologically established endemic. Similar to the diversity of freshwater mollusks, the abundance of land snails along the Dakil River in UPLLG is relatively low. Moreover, in terms of diversity, the area has a Shannon-Weiner value of 1.19 while the evenness value is 0.47. There are several factors that cause this low diversity index. First is the acidic nature of the rainforest soil in the area with a range of 5 to 6. Leaching of calcium, which is necessary for the egg and shell production of snails, is facilitated by active forest litter decomposition (Schilthuizen and Rutjes 2001; Schilthuizen et al. 2003). Second, all sites are exposed to anthropogenic activities such as illegal logging, slash-and-burn farming, and collection of timber and minor forest products for firewood and charcoal production (BirdLife International 2016). Resource extraction such as logging and wood harvesting is the top major threat to land snails. The demand for these resources results in modification or loss of the native forest habitat that eventually leads to the declining population of land snails (Parent 2008; Posa et al. 2008). Snails are characterized by low dispersal rate and vagility, which make them vulnerable to anthropogenic disturbance (Solem et al. 1981; Strayer et al. 1986). Loss of forest cover can lead to intense sun exposure, which land snails cannot tolerate. This causes desiccation, which leads to their mortality (Asami 1993; Douglas 2011; Hodges and McKinney 2018). Forest fragmentation caused by human-induced activities leads to less stable humidity and temperature microclimates in the tropical rainforest (Tattersfield et al. 2001). Waldén (1981) reported the decline of molluscan diversity because of forest canopy fragmentation that led to changes in sun and wind exposures, which directly affect snail survival. Structural simplification resulting in the conversion of indigenous forests to plantations may also lead to microclimate changes, and thus affect litter-dwelling species (de Chavez 2008). Changes in the distribution and abundance of individual land snail species in recent decades were documented as species have responded to land use pressures and climate change (Hawkins et al. 1997; Oke and Chokor 2009; Oke and Chokor 2011). This phenomenon was also observed in this study. The low diversity and abundance of land snails may be an indicator that the molluscan communities in the area have not yet recovered from the intense anthropogenic pressures that had dramatic effects on the snail population.

In a lotic environment, the abundance of freshwater mollusks is correlated with different environmental variables. In this study, the biplot correlated *Pomacea caniculata* and *Sinotaia angularis* to depth and temperature. Most aspects of *P. canaliculata* biology are strongly influenced by temperature, on which its growth rates are highly dependent (Estebenet and Martin 2002). In temperate climates, seasonality imposes interesting periods during which growth ceases almost completely (Estebenet and Cazzaniga 1992). In small streams, they remain motionless under boulders or while entangled in submerged plants with their cephalopodium partially withdrawn, but quickly become active when taken out of the water (Estebenet and Martin 2002). This phenomenon was also observed in this study. *Pomacea* and *Sinotaia* occurred exclusively in low-depth marshes with plenty of floating, emergent, and submerged vegetation (Estebenet and Martin 2002). *Pomacea canaliculata* are widely distributed throughout the tropical latitudes, occupying environments with slow flow or stagnant water (Thiengo 1995 cited by Giovanelli et al. 2005). *P. canaliculata* is among the 100 most invasive species in the world and is typically regarded as a pest in countries where it has been introduced—subsequently damaging crops and threatening native ecosystems (Naylor 1996; Cowie 2002; Carlsson et al. 2004 as cited by Tan et al. 2013). *C. fluminea* was inversely correlated to fast current with slightly acidic water. The abundance of *C. fluminea* generally increases with distance upriver and high sand content. Clams utilized all parts of the habitat in these systems, including sand, gravel, mud associated with marshes, the main channel, and depths up to 12.8 m (Freedman 2013). On the other hand, *Melanoides tuberculata*, *Stenomelania macilenta*, and *Radix quadrasi* were associated with substrate types and river velocity. *M. tuberculata* thrives in shallow, slow running water, and on soft mud and sand substrates—where they feed on microalgae, detritus, epiphytic algae, and decaying plants—and even on deep zones of freshwater pools composed largely of rocks. In the study of Giovanelli et al. (2005), *M. tuberculata* was strongly affected by water flow and rain distribution, which is the same in our study based on CCA. Prosobranchs prefer larger substrate as it provides a larger area for attachment, facilitates mobility, and is a source of algal assemblages and periphyton, the snails' preferred diet (Giovanelli et al. 2005; Martinez and Thome 2006). Thiarids are known to exhibit parthenogenesis and ovoviviparity, and have evolved a cephalic brood pouch from which their young emerge. This has facilitated their dispersal (Ben-Ami and Hodgson 2005). The parthenogenetic character, wherein most of the population are female, of the family Thiaridae may have contributed to their success and abundance in the five study sites examined. The pulmonate *Radix quadrasi* was positively correlated with different substrate types, i.e., mud, sand, pebble, and cobble. This species prefers slow-moving rivers with a muddy bottom. *Radix* sp. can live on boulders or in low or low high-flow environments and can tolerate anoxic conditions, but it tends to prefer very lentic waters like lakes, bogs or slow rivers where there is a silt substrate (Clarke 1981; Jokinen 1992; Sytsma et al. 2004). *Neritina* sp. was not related to the selected environmental variable. It was found at very low abundance (one in a single site), therefore it could not account for a direct relationship between the abiotic factors and the bivalves.

The biplot of land snail species, sampling sites, and environmental variables along the Dakil River in UPLLG showed that the dominant variables were altitude, soil pH, and the number of trees. It can also be seen in the CCA biplot that most of the land snail assemblage is located in an area opposite to the direction of the altitude and soil pH vector. Tattersfield et al. (2006) suggested that the diversity of mollusks is present at intermediate altitudes because of the faunal mixing of lowland and highland groups. It was observed that *Ryssota otaheitana* is closer to altitude and soil pH compared to other snail species. *Macrochlamys* sp. was not directly affected by the existing conditions in the secondary forests since it is considered an incidental collection. It was found on a banana plant trunk located between sampling sites. This is the limitation of CCA; *Macrochlamys* sp. was found only in a single site and thus was not directly related to the environmental variables mentioned in CCA. All generated axes (*p*-value of Axis 1 = 0.14; *p*-value of Axis 2 = 0.72) were significant at $p<0.81$ using the Monte Carlo Permutation Test. In terms of increase in species richness and abundance at lower altitudes, it may be related to the combined effects of low rainfall conditions at low elevations and increasing effect of soil leaching at high elevations, both of which may limit mollusk diversity and abundance (de Chavez 2008).

Land snail richness and abundance increase with increasing soil pH. Abundance and diversity depend on the factors underlying pH such as calcium and not directly on pH levels (de Chavez 2008). Calcium-poor sites are those that experienced slash-and-burn farming, which was evident in UPLLG in the 1920s until the 1990s when soil calcium was severely leached (Gonzalez 1995). However, one limitation of this study is soil exchangeable calcium was not measured.

Microhabitats can no longer support the nutrient requirements of the re-colonizing land snails (de Chavez 2008). This can potentially cause a lack of data on micro snails. Shells are largely made of calcium carbonate and, although a protein-based periostracum is present, this protective layer is often eroded at the top whorls, thus initiating shell breakdown under acidic conditions. In addition, Schilthuizen and Rutjes (2001) mentioned that acidic soil pH in rainforests is facilitated by a high rate of forest litter decomposition that causes leaching of minerals such as calcium, which is important to snails for shell and egg production.

In contrast with shells of living snails, dead and fossil shells were primarily affected by fragmentation, ornament loss, color loss, and carbonate coating. These taphonomic features fluctuated across time and space because of variable environmental conditions and/or time of exposure prior to shell burial (Yanes 2012).

The color loss and fragmentation were visible among the empty shells collected along Dakil River in UPLLG, some of which had partly eroded periostracum while others were severely bioeroded. This can be attributed to slightly acidic to slightly basic soil pH present in sampling sites. Moisture and low pH facilitate the rate of shell decomposition (Reitz and Wing 1999). On the other hand, alkaline soils rich in calcium delay this decomposition process (Schilthuizen and Rutjes 2001).

Being key prey to larger organisms or predators that crush and break their shells is another reason for the low diversity of land snails (Pearce 2008; de Chavez 2014). A terrestrial ecosystem is a hostile environment to land snails, which face a taxonomically wide range of predators (Barker 2004). Among the predators that feed on land snails is the threatened endemic Gray's monitor lizard (*Varanus olivaceus),* which is also known to occur in UPLLG (BirdLife International 2016). The diet of *V. olivaceus* (butaan) of Polillo Island and *V. bitatawa* of the Sierra Madre mountains of Northern Luzon consist almost entirely of fruits and snails (Bennett 2014; Law et al. 2018). They search for snails in decayed wood and on forest floors rather than in trees (Bennett 2014). Specifically, the most common snail included in the diet of butaan in Polillo are *Helicostyla* species (de Chavez 2014). After the butaan eats the snails, shells are usually crushed and discarded on the ground (Bennett 2014).

GLMM revealed the effect of single and combined environmental variables on species richness and abundance. Dominant variables were determined. In a global model using GLMM, the environmental variables affect the species richness and abundance of freshwater snails in the UPLLG watershed. It showed that species richness was highly affected by river velocity, while abundance was highly affected by temperature and inversely affected by canopy cover. Canopy cover decreased in the main river both upstream and downstream while the temperature was constant at 24°C. Current is the most significant characteristic of running water, and many stream animals are adapted to this. Freshwater organisms in the streams such as mollusks are highly adapted to rapid waters due to their conchological characteristics (turreted, cylindrical, or rounded shape). On the other hand, some gastropods such as *Pomacea canaliculata* and *Sinotaia angularis* preferred slow or non-moving water and low canopy cover. This can be explained by the light availability in non-shading areas that cause the abundance of algae, which serves as food for these gastropods. However, shading and nutrient limitation in forest streams usually result in low-standing stocks of algae (Dudgeon 2000), which are probably insufficient in terms of sustaining diverse molluscan communities. Surface runoff and decaying vegetation in forest streams also produce low pH waters, which can retard snail growth by increasing calcium dissolution rates (Johnson

1973; Dussart 1976; Hunter 1990). The frequency of *C. fluminea* in all sampling sites suggests that the bivalve species is adapted to both turbid and non-turbid water conditions with sandy stratum and slightly acidic water in Dakil River, UPLLG. In the study of Freedman (2013), *C. fluminea* abundance generally increases with distance upriver and high sand content. Clams utilized all parts of the habitat in these systems, including sand, mud associated with marshes, and the main channel. *C. fluminea* was found in mud, gravel, and depths up to 12.8 m. Prabhakar and Roy (2008) noted that gastropods exhibited a preference for still or slow-moving waters and extended their limits to fast-running waters. On other hand, bivalves generally colonized non-turbid water with a sandy substratum. The occurrence of bivalves is indicative of non-polluted water and oxygen-rich habitat so they may be considered as bioindicators in inland waters (Prabhakar and Roy 2008). The availability of a suitable microhabitat may determine the stream contribution of the freshwater mollusk (Bandel and Riedel 1998).

For land snails, after running the GLMM in a global model, the standardized parameter estimates revealed that altitude is the most significant predictor in determining the species richness of land snails along the Dakil River in UPLLG. In general, the estimated values showed an inverse relationship between the response variable and altitude, i.e. more species and more numerous individuals will be expected in the lowest altitude. In the case of abundance, canopy cover was also influential. Moreover, since the parameter estimate values were relatively close to each other, model averaging was implemented to generate sub-models to explain more clearly the above response variables by considering the top two $AIC_{c.}$ For species richness, altitude and null were the most parsimonious model; for abundance, it was canopy cover. Null means none of the mentioned environmental variables influence species richness.

Canopy gaps are characterized by having decreased humidity due to elevated temperature compared to close-canopy forests. Terrestrial gastropods are subjected to desiccation stress in these gaps. A study revealed that individuals of a common land snail in Montane Forest in Puerto Rico, *Caracolus caracolla* (L.), moved from canopy gaps to the closed-canopy forest (Bloch and Stock 2014). Both CCA and GLMM determine altitude as the major limiting factor for land snail diversity and abundance; however, these seem to be indirect relationships.

CONCLUSION

Corbicula fluminea is the most abundant freshwater mollusk while *Ryssota otaheitana* is the most abundant land snail along the Dakil River in UPLLG, Paete, Laguna. The diversity and abundance of both freshwater and land mollusks were low. Moreover, mollusks along the Dakil River have preferred microhabitats within the sites as supported by CCA biplots. Based on GLMM, the species richness of freshwater mollusks was highly affected by river velocity while the abundance was highly affected by temperature and inversely affected by canopy cover. For land snails, altitude was the most significant predictor for species richness and canopy cover for abundance. Existing microhabitats can no longer support the nutrient requirements of the re-colonizing land snails. Historical habitat destruction and modification might have caused low diversity in the snail population as reflected by the present data.

To further assess the malacofaunal diversity, it is recommended to conduct more sampling activities across UPLLG to generate more conclusive data on current molluscan populations. In addition, there should be an increase in the number of variables that might explain the diversity patterns for both freshwater and land mollusks. Moreover, a seasonal variation in the study of the malacofauna should be included for further study. Lastly, this study should also be replicated in various areas with similar historical environmental degradation episodes.

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