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Abundance and population profile of *Helicostyla daphnis* (Stylommatophora: Bradybaenidae), an endemic snail of Cebu, Philippines

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Abstract

Helicostyla daphnis is a tree snail endemic to Cebu, Philippines. The study aimed to survey and compare the abundance and population profile (by age category) of *Helicostyla daphnis* in North Cebu and South Cebu in relation to season and other physicochemical factors. Sampling was done twice between April and September 2013. For snail sampling, a standardized direct search equivalent to a two-hour sampling effort in a total of eighteen quadrats in six sites was used. Elevation, air temperature, relative humidity, surface soil pH, and soil exchangeable calcium were measured on each quadrat. Independent t-test and Pearson correlation were used to relate abundance to the physicochemical variables. Snail abundance was significantly higher ($p<0.01$) during the dry season (dry=783 snails; wet=436). South Cebu had higher total abundance (dry = 477; wet = 284) compared to North Cebu (dry = 306; wet = 152). Adult snails dominated at 87% of total abundance during the dry season and 74% during the wet season. Neonates were present only during the wet season, contributing 5% to total abundance. The presence of eggs in both seasons could mean year-round reproduction; but increased egg abundance and significant presence of neonates imply higher reproductive activity during the wet season. Relative humidity and air temperature were the identified major determinants of abundance as they affect the species' ability to avoid desiccation stress. The rate of harvesting of *H. daphnis* cannot also be ruled out as a factor affecting abundance between location.

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Introduction

The Philippines is one of the top biodiversity countries in the world. It is described by Heaney and Regalado (1998) as "the Galapagos Islands times ten" since every island (big or small) is a unique center of diversity—a host to many endemic species. Unfortunately, it is also one of the top biodiversity "hot spots" in the world, meaning the probability of a species going extinct is high. One of the leading causes of biodiversity loss is the destruction of habitat, such as the lowland tropical rain forests. The natural habitats gave way to massive human activities intended for economic gain, which led to serious consequences on the environment and on biodiversity.

Mollusks, the second most abundant invertebrate group (Abbott, 1989), has an estimated species richness of 80,000 to 135,000 species (van Bruggen, 1995). More than 35,000 of these mollusks are land snails (Solem, 1984), most of which are in the tropics. The Philippines alone houses 31% (22,000 out of 70,000 species) of all described mollusks with about 2-4% endemism (Vallejo 2002 cited in de Chavez and de Lara, 2011), but majority has remained undiscovered and undescribed.

The land snail genus *Helicostyla* is endemic to the Philippines. *Helicostyla daphnis*, a species of the genus is known to be endemic to Cebu; however, scientific literature on this specific snail is almost nonexistent. The few existing literature are mere short taxonomic descriptions of the species. *Helicostyla daphnis* (daphne helicostyla) is a member of genus *Helicostyla*—a group of small, terrestrial, pulmonate gastropods, in the family Bradybaenidae, subfamily Helicostylinae (Bouchet and Rocroi, 2005). It is described by Coney (2011) as a tree snail endemic to Cebu, first seen at high elevations in the rainforests of Barili, and is believed to be extinct due to the destruction of its natural habitat. Yet, of the Philippine land snail species, only *Helicostyla smargadina* (Reeve 1842) is listed in the International Union for the Conservation of Nature (IUCN) in 2008 as a critically endangered endemic species (de Chavez and de Lara, 2011). The fact that *H. daphnis* is currently exploited for food and shell trades in a municipality in northern Cebu, means the species is not yet extinct. However, the unregulated harvesting of this species in the wild could eventually lead to its endangerment and possible extinction. Unfortunately, conservation and protection measures cannot be properly initiated and implemented in the absence of scientific data on the snail's population status.

To fill the lack of baseline information on *H. daphnis*, rapid diversity surveys must be conducted. Basic documentation on the abundance and population profile of this snail species in relation to its habitat would therefore benefit the scientific and local communities. The entirely new data generated from this study could serve as basis for recommendations on how to sustainably harvest the snails so as not to compromise its population status.

This pioneering study generally surveyed and compared the abundance and population profile (classified according to age category: egg, neonate, juvenile or adult) of *Helicostyla daphnis* in North Cebu with that in South Cebu, Philippines in relation to season and other selected physicochemical factors.

Materials and methods

Study sites

Six vegetated sites in the municipalities of Borbon (S1 and S2), Sogod (S3) and Argao (S4, S5, S6), Cebu (Fig. 1) were the chosen locations for the conduct of the study. The municipalities of Borbon and Sogod represent North Cebu, while Argao represents South Cebu. Borbon is located in the northeastern part of Cebu Province, about 82.7 km from Cebu City. On its north is the municipality of Tabogon; the municipality of Sogod on its south; on the east is the Camotes Sea; and on the west are the municipalities of Tuburan and Tabuelan. South of Borbon is Sogod which is about 60.5 kilometers from Cebu City. It is bounded on the south by the municipality of Catmon;

on the east by the Camotes Sea; and on the west by the municipalities of Tuburan and Tabuelan. The municipality of Argao is 66.9 kilometers south of Cebu City. It is bounded in the north by the municipality of Sibonga, in the south by the municipality of Dalaguete, by Bohol Strait in the east and in the west by municipalities of Dumanhug, Ronda, Alcantara, Moalboal and Badian.

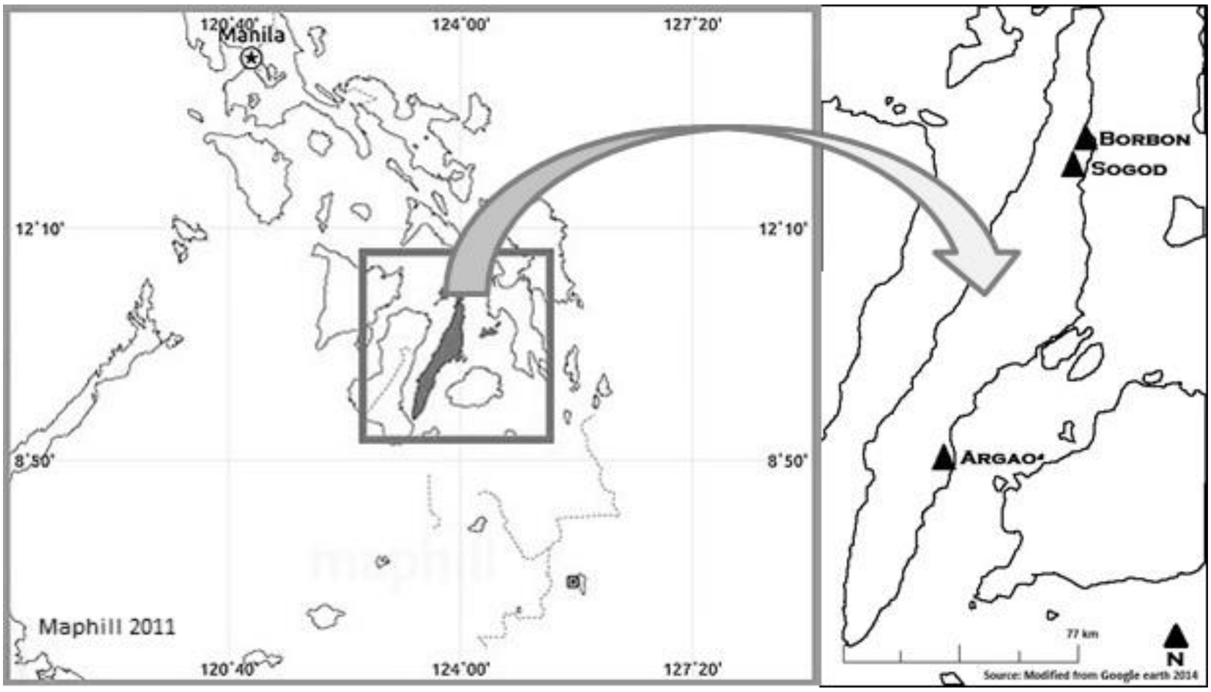


Fig. 1. Location map of the selected municipalities in North and South Cebu, Philippines where *Helicostyla dapnis* snails were surveyed (base maps from Maphill, 2011 and Google earth, 2014).

The choice of sampling sites was based on local community knowledge on where the snails are commonly found and harvested. Commercialization of *Helicostyla daphnis* snails was evident only in Borbon, North Cebu (Pinili, March 2011). The study sites in North Cebu had canopy cover of 30%-80%, while those in South Cebu ranged from 70%-90%. All sites had no original forest stands and showed signs of disturbance. A hand-held Global Positioning System (Garmin brand) was used to determine the geographic coordinates and elevation of the sampling sites.

S1 (10°49'30.9"N, 123°57'12.9"E; elevation: 184 masl; steeply sloping) was in a designated *H. daphnis* sanctuary in barangay Cajel (Fig. 2a). Typical of a disturbed habitat, this station had secondary growth, mixed species forest trees, with a reduced presence of large pioneering forest tree species. Trees observed include several *Ficus* sp., two *Macaranga* sp., *Buchanania arborescens* Blume, *Samanea saman* Jacq., *Senna siamea* L., *Annona muricata* L., *Alstonia scholaris* L., *Vitex parviflora* Juss., *Litsea bulusanensis* Elmer, *Glochidion camiguinense* Merr., *Pittosporum resiniferum* Hemsl., *Morinda citrifolia* L., and *Citrus* sp. One orchid species *Cattleya labiata* Lindl. and a species of liana were also present. Ground vegetation was absent.

(a) (b)

Fig. 2. The distribution of sites at which *Helicostyla daphnis* snails were sampled. (a) North Cebu, (b) South Cebu (base map from Google earth, 2014).

S2 (10°49'11.1"N, 123°59'9.4"E; elevation: 265 masl; gently sloping) was a tree plantation site in barangay Lugo (Fig. 2a). Vegetation was dominated by *Leucaena leucocephala* Lam. and *Cocos nucifera* L. However, there were also other tree species such as *Buchanania arborescens*, *Ficus benjamina* L., *Ficus septica* Merr., *Saurauia confusa* Merr., *Alangium javanicum* Blume, *Chrysophyllum cainito* L. and *Heterospathe elata* Scheff. A vine species *Syngonium angustatum* Schott was also spotted.

S3 (10°47'56.9"N, 123°59'35.6"E; elevation: 132 masl; and 10°47'23.0"N, 123°59'47.9"E; elevation: 148 masl; gently to steeply sloping) in barangay Liki (Fig. 2a) was characterized by the presence of mixed species of trees (e.g. *Leucaena leucocephala*, *Cocos nucifera*, *Buchanania arborescens*, *Ficus benjamina*, *Ficus septica*, *Mallotus philippinensis* Lamk., *Glochidion camiguinense* Merr., etc.), shrubs (e.g. *Chromolaena odorata* L.), vines (e.g. *Cissampelos pareira* L.), and grasses (e.g. *Imperata cylindrica* L.), typical of a disturbed habitat. Ground cover was mostly carabao and cogon grasses. Quadrat 1 was beside an open pasture where a few ruminants were grazing.

S4 (09°58'15.9"N, 123°32'48.7"E; elevation: 321 masl; gently to steeply sloping) in barangay Colawin (Fig. 2b). There were secondary growth trees (e.g. several *Ficus* sp., *Neonauclea formicaria* Elmer, *Glochidion camiguinense*, *Manikara zapota* L. van Royen, *Flacourtia rukam* Zoll. & Moritzi, *Cordia dichotoma* Forst. f., *Kibara coriacea* Perk., *Morinda citrifolia* L., etc.) mixed with planted species (e.g. *Swietenia mahogani* L., *Cocos nucifera* L.). There were also shrubs (e.g. *Chromolaena odorata*, *Lantana camara* L.), vines (e.g. *Cissampelos pareira*) and fern (*Lygodium flexuosum* L. Sw.). Instead of ground vegetation, leaf litter cover the forest floor.

S5 (09°58'17.7"N, 123°32'39.3"E; elevation: 277 masl; gently sloping) was in barangay Lengigon, named by the locals as upper Lengigon (Fig. 2b). The site had mixed vegetation, of vines, shrubs, and secondary growth trees. Most of the species found in S4 were also found in S5. Vegetation not found in S4 but present in S5 include *Breynia oblongifolia* Muell.Arg., *Pandanus monticola* F.Muell., *Bambusa spinosa* Roxb., *Leea indica* (Burm. f.) Merr., *Calamus merrillii* Becc., *Premna vestita* Schauer, and *Areca catechu* L.

S6 (09°58'19.1"N, 123°32'36.0"E; elevation: 273 masl; gently sloping) was also in barangay Lengigon, named by the locals as lower Lengigon (Fig. 2b). The site also had mixed vegetation of vines, shrubs, and secondary growth trees, not much different from the previous two sites. However, it had unique vegetation such as *Syzygium cumini* (L.) Skeels, *Pithecellobium dulce* (Roxb.) Benth., *Melia dubia* Cav., *Sapium sebiferum* (L.) Roxb., *Mangifera laurina* Blume, *Schefflera elliptica* (Blume) Harms, and *Cardiospermum halicacabum* L.

Sampling and measurements

Sampling was done twice in a year in each site, once during the dry season (Apr 3, 4 and 6, 2013) and once during rainy season (Aug 25 and Sep 8, 2013), between 0600-1100 h and 1500-1800 h. Cebu's climate falls under Climate Type III with rainy season from May to November, and dry season from December to April (Malaki *et al.*, 2013). For every sampling, three 20m x 20m quadrats were laid out at each of the 6 sites, totaling 18 quadrats and 7200 sqm of sampled area. The quadrats were established 50 m away from each other to avoid pseudoreplication. For each quadrat, four persons extensively searched for live *H. daphnis* snails equivalent to a two-hour sampling effort, paying particular attention to the stems, branches, trunks, and undersides of leaves of grasses, herbs, vines, shrubs and trees (de Chavez and de Lara 2011). All accounted *H. daphnis* snails were categorized into age categories (Fig. 3): egg, neonate (newly hatched up to <1cm or 10mm), juvenile (>1cm or 10mm but not >4cm or 40mm), and adult (4cm or 40mm and bigger and characterized by the presence of a shell lip).

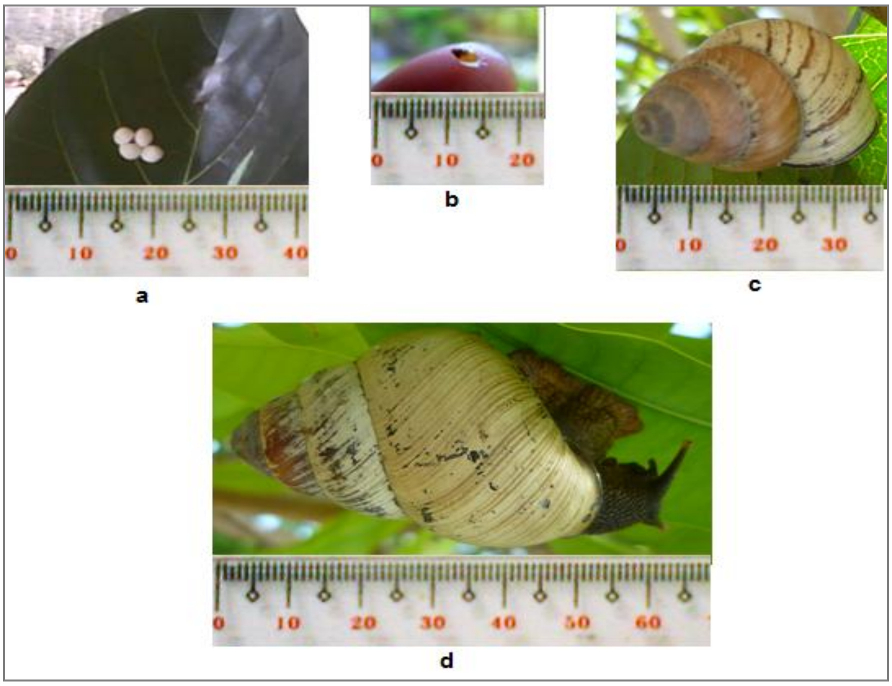


Fig. 3. *Helicostyla daphnis* at different age categories, with the corresponding sizes (in mm): (a) egg, (b) neonate (photo courtesy of Mr. Patrick Fortunato), (c) juvenile, and (d) adult.

Selected physicochemical variables were measured and recorded on each quadrat. On-site measurements were done in replicates for air temperature, relative humidity, and surface soil pH using pre-calibrated instruments. Air temperature was determined by suspending a field thermometer at least 2 m above the ground. Relative humidity was measured using a hand-held sling psychrometer. A pen type pH meter (HM brand) was used to measure the soil pH. Surface soil subsamples (upper 5 cm) approximating 500 g were collected from several points in each quadrat and then composited, air-dried, and pulverized. All soil samples were brought to a reliable and certified laboratory (Technolab) for the determination of soil exchangeable calcium using atomic absorption spectrophotometer (AAS).

Data analyses

Snail species abundance was measured based on the number of individuals counted in each quadrat. To determine significance of the relationship of more than two variables (e.g., physicochemical parameters at the different locations during the different seasons) the independent samples t-test was used. Pearson correlation analysis was also used to determine the magnitude (significant or strongly significant) and direction (negative or positive) of the relationship between variables (e.g., abundance and certain physicochemical variable) especially those found to be significantly different in space and time. The physicochemical and biological variables were subjected to the Statistical Package for Social Sciences (SPSS) Version 19 (trial version).

Results

Physicochemical component

Tables 1 and 2 show the summary of the physicochemical readings by location and season. Relative humidity was generally high and ranged from 60% to 93% with the lowest recorded reading of 60% observed in S2 (Lugo, Borbon) of North Cebu during the dry season; the highest reading of 93% was recorded in S6 (Lower Lengigon, Argao) of South Cebu during the wet season. The generally basic soil pH readings ranged from 7.1 to 9.0 with the lowest reading observed in S1 (Cajel, Borbon), North Cebu during the wet season; the highest pH reading was recorded in S3 (Liki, Sogod), also of North Cebu during the dry season. Soil exchangeable calcium ranged from 0.10 mg/g to 305.97 mg/g. The lowest reading was recorded in North Cebu (S1) while the highest was at S4 (Colawin, Argao), South Cebu. The study sites were at elevations between 100 to 300 masl. North Cebu (S3) had the lowest elevation of 132 masl, while South Cebu (S4) had the highest at 321 masl. Air temperature readings ranged from 25^{o}C-35^{o}C with the lowest reading recorded in North Cebu (S1) and South Cebu (S2) during the wet season, and the highest reading observed at North Cebu (S1) during the dry season.

Table 1. The mean ± SE (minimum and maximum values in parentheses), F-value and level of significance of each physicochemical parameter and *Helicostyla daphnis* abundance for each age category, by location, Cebu, Philippines, 2013.

Parameter	Location 1 (North Cebu)	Location 2 (South Cebu)	F-value	Sig. (2-tailed)
Relative humidity (%)	71.54 ± 1.01 (60 - 90)	82.02 ± 1.07 (60 - 93)	0.02	.000*
Soil pH	8.05 ± 0.06 (7.1 - 9.0)	8.05 ± 0.04 (7.3 - 8.5)	5.72	.960
Soil calcium (mg/g)	45.66 ± 7.34 (0.10 – 161.83)	265.95 ± 3.55 (217.90 – 305.97)	37.01	.000*
Elevation	197.22 ± 12.37 (132 - 265)	290.33 ± 5.27 (273 - 321)	16.95	.000*
Air temperature (^{o}C)	28.54 ± 0.38 (25 - 35)	28.34 ± 0.18 (25.4 - 31)	29.16	.620
Neonate (N)	0.67 ± 0.33 (0 - 4)	0.44 ± 0.20 (0 - 2)	1.98	.572
Juvenile (J)	6.44 ± 1.03 (1 - 17)	4.50 ± 0.79 (0 - 11)	0.64	.142
Adult (A)	18.33 ± 5.07 (2 - 77)	37.33 ± 3.77 (15 - 72)	0.33	.005*
Total (N+J+A)	25.44 ± 5.31 (6 - 83)	42.28 ± 3.95 (16 - 75)	0.29	.016*
Eggs	1.00 ± 1.00 (0 - 18)	7.00 ± 5.53 (0 - 100)	0.24	.735

* the mean difference is significant at $p<0.05$ level (independent samples t-test)

Table 2. The mean ± SE (minimum and maximum values in parentheses), F-value and level of significance of each physicochemical parameter and *Helicostyla daphnis* abundance for each age category, by season, Cebu, Philippines, 2013.

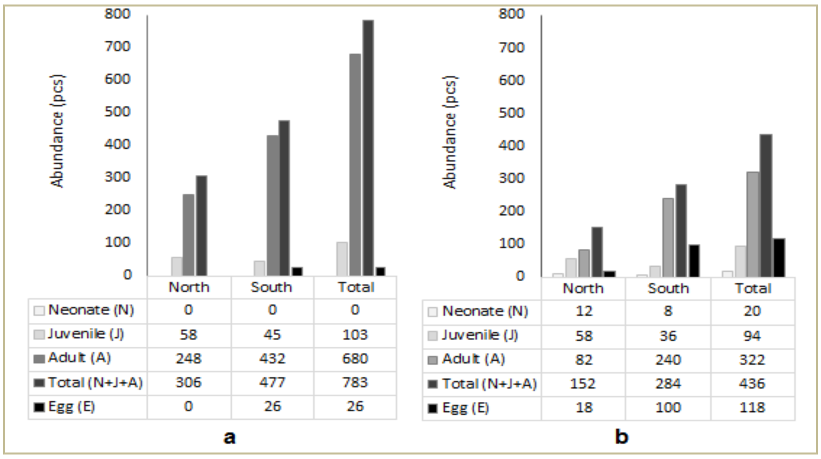
Parameter	Dry (April)	Wet (Aug & Sep)	F-value	Sig. (2-tailed)
Relative humidity (%)	75.72 ± 0.94 (60 - 88)	77.83 ± 1.51 (64 - 93)	57.65	.239
Soil pH	8.04 ± 0.06 (7.2 - 9.0)	8.06 ± 0.04 (7.1 - 8.5)	18.51	.802
Soil calcium (mg/g)	155.478.74 ± 16.80 (0.10 – 305.97)	156.13 ± 15.55 (1.00 – 300.40)	1.763	.977
Air temperature (°C)	29.54 ± 0.30 (25.4 – 35.0)	27.34 ± 0.19 (25.0 – 30.0)	4.39	.000*
Neonate (N)	0.00 ± 0.00	1.11 ± 0.34 (0 - 4)	61.06	.005*
Juvenile (J)	5.72 ± 1.07 (0 - 17)	5.22 ± 0.79 (1 - 14)	1.81	.710
Adult (A)	37.78 ± 5.58 (5 - 77)	17.89 ± 2.80 (2 - 42)	8.13	.004*
Total (N+J+A)	43.50 ± 5.80 (6 - 83)	24.22 ± 2.76 (6 - 45)	10.21	.006*
Eggs	1.44 ± 0.83 (0 - 12)	6.56 ± 5.59 (0 - 100)	0.24	.735

* the mean difference is significant at $p<0.05$ level (independent samples t-test)

Of the physicochemical parameters measured, relative humidity, soil exchangeable calcium and elevation varied significantly ($p<0.001$) with location (Table 1), with higher readings observed in South Cebu. Meanwhile in Table 2, only air temperature showed significant seasonal variability ($p<0.001$), with higher readings recorded during the dry season.

Snail abundance

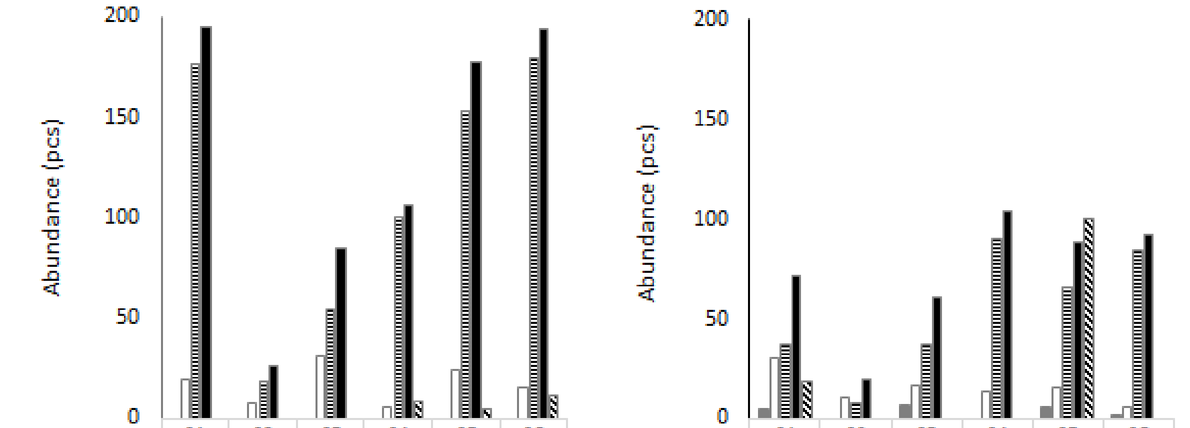
Figure 4 shows a total count of 783 snails or a density of 0.109 ind/m² during the dry season, the distribution of which was: 103 juveniles, 680 adults, and 0 neonate. During the wet season sampling, there were 436 individuals recorded or a density of 0.061 ind/m² distributed as follows: 20 neonates, 94 juveniles, and 322 adults. Tables 1 and 2 show that total abundance was significantly different between location ($F=0.29$, $p<0.05$) and season ($F=8.13$, $p<0.01$). South Cebu showed higher total snail abundance for both seasons (dry = 477; wet = 284) compared to that in North Cebu (dry = 306; wet = 152), however, the numbers decreased in both locations during the wet season sampling (Figs. 4 and 5).



a	North	South	Total
Neonate (N)	0	0	0
Juvenile (J)	58	45	103
Adult (A)	248	432	680
Total (N+J+A)	306	477	783
Egg (E)	0	26	26

b	North	South	Total
Neonate (N)	12	8	20
Juvenile (J)	58	36	94
Adult (A)	82	240	322
Total (N+J+A)	152	284	436
Egg (E)	18	100	118

Fig. 4. Abundance of *Helicostyla daphnis* classified according to age category (neonate, juvenile, adult, egg), location (North and South Cebu), and season, (a=dry, and b=wet).



	S1	S2	S3	S4	S5	S6
Neonate (N)	0	0	0	0	0	0
Juvenile (J)	19	8	31	6	24	15
Adult (A)	176	18	54	100	153	179
Total (N+J+A)	195	26	85	106	177	194
Egg	0	0	0	9	5	12

a

	S1	S2	S3	S4	S5	S6
Neonate (N)	5	0	7	0	6	2
Juvenile (J)	30	11	17	14	16	6
Adult (A)	37	8	37	90	66	84
Total (N+J+A)	72	19	61	104	88	92
Egg	18	0	0	0	100	0

b

Fig. 5. Abundance of *Helicostyla daphnis* classified according to age category (neonate, juvenile, adult, egg), sampling site (S1, S2, S3, S4, S5, S6), and season, (a=dry and b=wet).

Adult snail count for the sampling sites ranged from 8 to 179 individuals (Fig. 5). The most number of adults was recorded at South Cebu (S6) during the dry season, while the least count was at North Cebu (S2) during the wet season. Juvenile abundance ranged from 6 to 31 individuals. The least number of 6 individuals was recorded at South Cebu (S4, dry season; S6, wet season), while the most number was observed at North Cebu (S3, dry season). Neonate count ranged from 0 to 7. No neonates were observed in the dry season. The highest count of 7 was recorded in North Cebu (S3) during the wet season sampling. Adding together the neonates, juveniles and adults, total abundance ranged from 19 in North Cebu (S2) during the wet season, to 195 also in North Cebu (S1) during the dry season. *H. daphnis* eggs were found in S4 and S5 (upper Lengigon, Argao) during the dry season, and in S1 and S5 during the wet season.

Population profile

Figure 6 shows the composition of the sampled snails by age category and by season. The adult snails were the most dominant of the age groups with significant spatial ($F=0.33$, $p<0.01$) and seasonal ($F=8.13$, $p<0.01$) variability in abundance leading to a significant difference in total abundance ($F=61.06$, $p<0.01$) between season (Tables 1 and 2). It comprised 87% of total snail abundance during the dry season and 74% during the wet season. Although juvenile abundance was generally higher in North Cebu during the dry season (Figs. 4 and 5), the difference was not significant ($p>0.05$; Tables 1 and 2). Neonates were absent during the dry season but had a significant presence during the wet season ($F=61.06$, $p<0.01$), contributing 5% to the total snail abundance (Fig. 6b). Egg abundance was observed to be higher during the wet season especially in South Cebu (Figs. 4 and 5), however, the difference in numbers was not significant ($p>0.05$; Tables 1 and 2).

Table 3 shows the relationship between the physicochemical parameters and snail abundance. The total snail abundance had a significant negative correlation with season ($r = -0.458$, $p<0.01$) and soil pH ($r = -0.378$, $p<0.05$), but was positively correlated with location ($r = 0.400$, $p<0.05$), relative humidity ($r = 0.381$, $p<0.05$) and air temperature ($r = 0.385$, $p<0.05$). Looking at relationships between age categories and the physicochemical parameters, the neonates and the juveniles were each correlated to only one of the parameters measured. The former had a significant positive correlation with season (r = 0.487, p<0.01), while the latter showed a negative relationship with elevation (r = -0.470, p<0.01). The adult group, similar to total abundance, had the most significant correlations with the physicochemical parameters. It was positively correlated with location (r = 0.458, p<0.01), relative humidity (r = 0.420, p<0.05) and air temperature (r = 0.449, p<0.01); but negatively correlated with season (r = -0.480, p<0.01) and soil pH (r = -0.373, p<0.05). Meanwhile, soil calcium was not correlated to any age category nor to total abundance. Likewise, the egg category failed to correlate with any physicochemical parameter.

Table 3. Pearson correlation coefficient between selected physicochemical factors and abundance of *H. daphnis* at the egg, neonate, juvenile, adult stages, and with total abundance.

Physicochemical variables	Abundance				
	Neonate	**Juvenile**	**Adult**	**Total (J+A+N)**	**Egg**
Season	.487**	-	-.480**	-.458**	-
Location	-	-	.458**	.400*	-
Relative humidity	-	-	.420*	.381*	-
Soil pH	-	-	-.373*	-.378*	-
Soil calcium	-	-	-	-	-
Elevation	-	-.470**	-	-	-
Air temperature	-	-	.449**	.385*	-

* correlation is significant at the 0.05 level (2-tailed)
** correlation is significant at the 0.01 level (2-tailed)

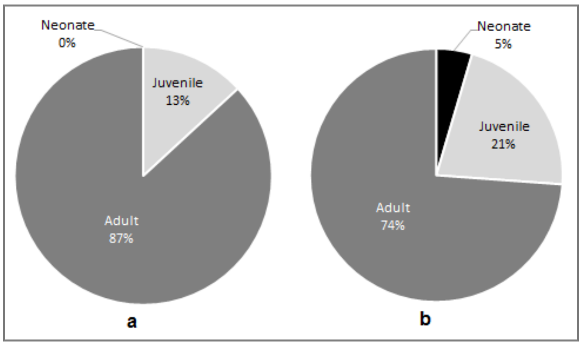


Fig. 6. Population profile of *Helicostyla daphnis* in Cebu (composite for North and South) during the (a) dry season, and (b) wet season.

Fig. 7. Eggs of *Helicostyla daphnis* are deposited in a "nest" made of leaves rolled into cornucopia (photo courtesy of Ms. Ellen Funesto).

Discussion

South Cebu had more *Helicostyla daphnis* individuals than North Cebu in all sampling occasions. While the adults were frequently encountered in all locations during the different seasons, they were especially abundant during the dry season resulting to a higher total abundance for the season. Meanwhile, neonates were significantly present only during the wet season. The difference in abundance across location and season, and between age categories could probably be a result of differences in environmental variables. There was significant physicochemical variation between the two study locations, with most variables being different except for soil pH and air temperature. The factors which seem to be of influence in the variation in abundance of *H. daphnis* between location (South and North Cebu) are relative humidity, soil exchangeable calcium and elevation. Except for soil exchangeable calcium, all environmental factors showed significant correlations (positive or negative) with at least one of the age categories and/or with total abundance.

The higher relative humidity in South Cebu could have made the environment ideal for the growth and reproduction of *H. daphnis*, hence the higher abundance in this area. The importance of relative humidity to *H. daphnis* is further strengthened by its significant, positive correlation with total abundance. Snail activity, depending on species, could be influenced by physicochemical factors such as temperature, humidity, light intensity, soil conditions and food supply (Sallam and El-Wakeil, 2012). Snails are ectothermic and relatively susceptible to desiccation stress (Cook 2001) so that in order to sustain an active life (i.e. dispersal and reproduction), they need an environment with high humidity (Baker, 1958). Sallam and El-Wakeil (2012) reports that reproductive behavior for snails is initiated only when the humidity is at 80-85%. Barrientos (2000) in a study of *Ovachlamys fulgens*, also reveals that high relative humidity is an important factor for snail and egg abundance due to the snails' trail production of slime and the nature of the eggs to readily absorb moisture (Barrientos, 2000).

Another factor that contribute to desiccation stress of land snails is air temperature. Snails, being not quite vagile, are prone to desiccation due to higher temperature (Cook, 2001). The observation that land snail abundance, richness and/or distribution often correlates negatively with air temperature (e.g. Barrientos, 2000; Patil *et al.*, 2012) does not agree with the results of this study since there were more *H. daphnis* individuals (especially the adults) in both locations during the dry season where air temperature was significantly higher. This result though is not particularly unique as some studies of land snails, depending on species, have also yielded similar results (e.g. Alonso and Berovides, 1991; Alvarez, 1991). The island of Cebu has a noted dry season and receive much lower rainfall throughout the year (Miclat *et al.*, 2004). *H. daphnis*, as a native species of Cebu, could have developed adaptations to avoid desiccation in a constantly warm tropical environment. In fact, Henwood (1975) presents that behavioral plasticity is not an uncommon mode of thermoregulation by invertebrates. Some of the more common land snail behavioral adaptations to increase heat resistance and avoid high environmental temperatures that are also observed in *H. daphnis* include: climbing on elevated objects (i.e. vegetation) in order to escape heat coming from the ground (Pomeroy, 1968; Yom-Tov, 1971); remaining inactive and attached to elevated objects (i.e. stems of vegetation) during hot daytime periods (Dittbrenner *et al.*, 2009); and choosing resting sites that are sheltered from the sun and wind, and orienting the shell to facilitate heat flow (McQuaid *et al.*, 1979; Cowie, 1985).

Another possible factor affecting *H. daphnis* abundance was the soil exchangeable calcium, the amounts of which were much higher in South Cebu than in North Cebu. Literature is abound with studies of land snails showing a significant and positive correlation between soil calcium and snail abundance, richness and/or distribution (e.g. Ondina *et al.*, 1998; Tattersfield *et al.*, 2001; Hotopp, 2002; Juřičková *et al.*, 2008; Beier *et al.*, 2012). Calcium availability in the soil is important for land snails as it is required for shell formation (Sen *et al.*, 2012); it is a major component of gastropod shells and opercula, and even the eggs (Dallinger *et al.*, 2001). In egg formation, calcium carbonate ($CaCO_3$) crystals are deposited in the outer layers of the egg either as discrete crystals dispersed in the jelly matrix or in quantities as to form a hard, brittle shell of fused crystals of $CaCO_3$ (Heller, 2001). Shelled eggs are common in at least 36 stylommatophoran families (Tompa, 1976). Soil exchangeable calcium, however, could be considered as a weak predictor for *H. daphnis* abundance since it did not show significant correlation to any age category or to total abundance. This could be because *H. daphnis* is a truly arboreal species where its full life cycle, including egg deposition, occur in trees. Similar to *Helicostyla pithogaster*, eggs are deposited in a “nest” made of leaves rolled into cornucopia (Fig. 7), stuck together and lined with mucus (Heller, 2001). Since there is no existing published literature on *H. daphnis*, personal observations on the field and informal interviews with the locals were done to get some information on the behavior of this endemic snail. The common observations include: 1) the snail does move around within a tree or plant, or from plant to plant or tree to tree and migration could have occurred at nighttime; 2) during daytime the animals are usually seen not moving and remain attached under the leaves of plants; 3) the species is seldom (if not at all) seen crawling on the ground/soil, while those seen on the ground/soil, are attacked by ants leading to death; and 4) the shell of this snail darkens when wet. With the third observation, it can be assumed that migrating snails would avoid the ground or soil as much as possible. In this case, this arboreal snail species may not be able to get the calcium for its needs directly from the soil. However, Horner and Wagner (1980) explain that tree snails could get their calcium transported directly from soil solution through plants; but the calcium must be in soluble citrate form for easy assimilation by snails (Wäreborn, 1969).

Unlike soil exchangeable calcium, surface soil pH in this study did not significantly vary between location and season. According to Nekola and Smith (1999), calcium and pH may not always have the same effect on land snails. The correlation results however, revealed a significant negative correlation between soil pH and adult *H. daphnis* and total abundance. This result is not in agreement with existing literature on the positive relationship between snail abundance and soil pH (e.g. Tattersfield *et al.*, 2001; Schilthuizen *et al.*, 2003; Martin and Sommer, 2004). This could be because the pH values in all sites were all high (basic), with no value below pH 7.1. The major influence on hydrogen ions and the parameters affecting alkalinity and acidity is the geology of the watershed. Cebu is made up mostly of tertiary and quaternary limestone of coralline origin (Talisay CPDO, 2001), which is dominantly composed of the calcium-bearing carbonate mineral calcite (Tarbuck *et al.*, 2013). A high soil pH implies richness in carbonates, bicarbonates, and associated salts that come from the dissolution of limestone (Smith and Smith, 2000).

Elevation could be another contributing factor to differences in abundance of *H. daphnis* between locations. Cebu island has a rugged, but not particularly high mountain range running the entire length of its interior (Miclat *et al.*, 2004). Although elevation alone does not affect snail population in relatively low mountains, the abundance peaks for endemic snails are along the intermediate elevation and decline as altitude increases (Lomolino, 2001). In a study of snails in Mt. Makiling forest reserve in the Philippines, elevation was not a predictor of snail abundance, however, abundance was observed to be highest along the middle elevation (de Chavez and de Lara, 2011). Liew and colleagues (2010) similarly supports that although species density decreases significantly with increasing elevation, highest diversity and highest abundance at species level occur at the mid-altitude. Cebu's highest peak (Osmena Peak, Mantalungon, Dalaguete, Cebu) is about 1,000 masl (Malaki *et al.*, 2013), so mid-altitude range could be from 400 masl-600 masl. The study sites in South Cebu, at 273-321 masl, may not be exactly at mid-altitude relative to the highest peak, however, these elevations are much nearer the middle elevation range compared with those in North Cebu (132 masl-265 masl). This observation however applies only to this study and should not be considered as conclusive. Snail abundance data for elevations above 321 masl and below 132 masl are needed to verify the effect of elevation on the abundance of *H. daphnis*.

The dominance in abundance of the adult *H. daphnis* among the different age categories could be attributed to differences in morphology, physiology and behavior leading to differences in tolerance to environmental stressors. One of the main problems of land snails is their vulnerability to desiccation, hence they have developed adaptive mechanisms to avoid desiccation stress. Perrot and colleagues (2007) reports that adult snails have small aperture:size ratio and thicker shell. In land snails, desiccation stress brought about by high temperature and low moisture is decreased with a small aperture:size ratio (proportional size of aperture relative to shell size), and thicker shells. Ratio was observed to be smallest in adults, and largest in the medium- and small-sized, while small snails had thinner shells (Perrot *et al.*, 2007). Another reason could be that the younger snails (i.e. neonates and juveniles) are more inconspicuous leading to their under assessment. Schilthuizen and Rutjes (2001) in their study of land snail diversity in a rainforest in Borneo observes that all abundant species they have recorded are the very large and conspicuous ones, which suggests that many small ones were overlooked. This could be because the smaller snails being more vulnerable to desiccation, have the tendency to occupy less exposed microhabitats (Heatwole and Heatwole, 1978); or have climbed to much higher layers of vegetation as a behavioral adaptation (Pomeroy, 1968; Yom-Tov, 1971). The degree of exploitation through harvesting of the *H. daphnis* for food and other purposes cannot be ruled out as another reason for the difference in abundance between location. It should be noted that this edible tree snail is already commercially sold in Borbon, North Cebu, but not in South Cebu. Predation pressure (Baur *et al.*, 2007) as well as anthropogenic pressure and land use pattern (Patil *et al.*, 2012) are also reported to affect molluscan diversity and abundance.

The presence of *H. daphnis* eggs in both seasons could mean that the species reproduces during the entire year. However, the increase in abundance of the eggs and the significant presence of the neonates during the wet season could be an implication of higher reproductive activity during this season compared with the dry season. This observation is in agreement with that of Barrientos (2000) where the neonate group decreased during the dry season but increased most dramaticalIy with the rains.

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