TERRESTRIAL GASTROPOD DISTRIBUTIONAL FACTORS: NATIVE AND NONNATIVE FORESTS, ELEVATION, AND PREDATION ON MO'OREA, FRENCH POLYNESIA

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Abstract. The factors contributing to biodiversity of terrestrial gastropods on Mo'orea, French Polynesia are investigated. Gastropods are sampled from four native forests of predominately *Hibiscus tiliaceus*, and four nonnative forests of predominately *Falcataria moluccana* within two elevational ranges. It is determined that the type of forest has an effect on the species composition of that habitat. Additionally, it is determined that elevation is a determinant in relative species composition. An additional variable possibly contributing to species distribution is the predatory detection of the introduced flatworm, *Platydemus manokwari*, by two predominant species of this study. This is primarily a study on the current biodiversity of a vastly neglected group of molluscs on island of Mo'orea.

Key words: terrestrial gastropods; Falcataria moluccana; Hibiscus tiliaceus; Georissa sp.; Ovachlamys fulgens; Platydemus manokwari; *native forests*; *nonnative forests*; *Mo'orea*

INTRODUCTION

With global declines of biodiversity worldwide and species extinctions increasing at rapid rates, it has become an urgent matter to assess biodiversity (Lydeard et al. 2004, Novacek and Cleland 2001). The past 300 years have seen an increase in extinctions by several hundred times compared to the geological record of extinctions (Dirzo and Raven 2003). Efforts toward conservation are hindered by insufficient knowledge of species distribution and the various threats to biodiversity, such as habitat loss and alteration, introduced species, and various other human impacts (Lydeard et al. 2004). In order to begin conservation, biodiversity information is required.

Phylum Mollusca is the second largest phylum of animals with representatives in multiple marine, freshwater and terrestrial environments (Cowie 2001). Among molluscs, gastropods incorporate over 62,000 described extant species with estimates of over 80,000 more species left to be described (Bunje 1999). Within gastropods there are 24,000 described terrestrial species with estimates of 11,000 to 40,000 undescribed species. There are clearly many species left to be described and molluscs are disappearing faster than they can be documented. Since the year 1500, 42% of documented extinctions have been molluscs and 99% of those were nonmarine molluscs (Lydeard et al. 2004).

Biodiversity of land snails in tropical and sub-tropical Pacific islands is estimated to be around 5,000 species, most of which are endemic to single islands or archipelagos. Alien species, introduced both intentionally and unintentionally, are only estimated to be around 100 or so. However, like the giant African snail, *Achatina fulica*, they often outcompete endemic snails. In the case of the rosy wolf snail, *Euglandina rosea*, invasive species simply prey on endemic snails, and thus can lead to drastic declines and extirpations of endemic snail populations such as *Partula* (Cowie 1992, Cowie 2004). *Euglandina rosea* was introduced as an ill-conceived biological control on exploding populations of *A. fulica* (Cowie 2004). Such introduced species pose a great threat to ecosystems, especially on islands where space is very limited. This system is compelling and unique with *Partula* as the poster snail for conservation; however, there is no like

concern or assessment of the many other land snails (Cowie 2004).

The biodiversity of land snails urgently needs to be documented on remote islands of the Pacific (Cowie 2004), such as Mo'orea. There could be many species of land snails on Mo'orea that are suffering drastic drops in biodiversity without our knowledge. There is a lack of any recent formal species list for Mo'orea (Cowie pers. comm.) and any insight into the present biodiversity of Mo'orean land snails would be a step in the right direction to begin conservation.

Studying biodiversity of gastropods inhabiting leaf litter on Mo'orea could simultaneously lead to the discovery of new species, as well as help indicate ecosystem structure and health in various habitats (Cowie 2004). Also, terrestrial gastropods hold significant roles in soil transformation and constitute an important level in terrestrial food webs. They also are good indicators of soil calcium levels (Madhyastha et al. 2001).

Ideally, an extensive distributional study of the entire island of Mo'orea should be conducted, but given the limited time constraints of this study, a focused sampling to assess biodiversity was employed. It has been previously noted that species *Georissa sp.* preferentially select *Hibiscus tiliaceus* leaf litter over *Inocarpus fagifer* leaf litter for unknown reasons (McNaughton 2007). *Hibiscus tiliaceus* dominated forests were used in this study as the designated "native" forest due to this preference and *Falcataria moluccana* was used for the "nonnative" forest, as its invasion is a threat to native ecosystems such as *H. tiliaceus* (Hughes and Denslow 2005, Meyer 2004). This study attempted to document relative distributions of leaf-litter gastropods in the Opunohu valley using native and nonnative canopy cover at low and mid elevations. Gastropod communities under nonnative canopy cover are hypothesized to be different from native canopy cover as are communities of mid elevations compared to low elevations.

A second component of this study investigated the predator awareness of the two most common species found while sampling. It is hypothesized that predator awareness in Species A and Species B is a factor in these species broad distributions.

METHODS

Biodiversity study sites

This study was conducted in the Opunohu Valley of Mo'orea Island, French Polynesia from September through November of 2009. Mo'orea is a part of the Society Island Archipelago, located approximately 17km northwest of Tahiti in the South Pacific. The following study sites on Mo'orea were located in the Opunohu Valley area: (1) in or near the Amehiti Valley in the "Proposed Pineapple Plantation" (PPP); (2) on the property of the Agriculture School (AgS); at locations close to Belvedere (Belv), and at locations close to Three Coconuts pass (3Coco) (Fig. 1). I described terrestrial gastropod biodiversity from eight paired locations based on "native" and "nonnative" canopy cover and elevation (Table 1). Voucher specimens were collected, preserved, and transported back to University of California, Berkeley.

Field sampling and collection

Sites were chosen based on forest composition. Native canopy cover consisted primarily of *Hibiscus tiliaceus* and *Neonauclea forsteri* (at Belvedere native site). Regrettably, *Inocarpus fagifer* is a very predominant Polynesian introduced tree on Mo'orea, and almost every native site (except the higher mid elevation site, 3Coco native) contained this pervasive species to some extent. Nonnative canopy cover consisted of primarily *Falcataria moluccana* stands. Two low elevation sites (in Amehiti Valley and near the Agriculture School) and two mid elevation sites (off trails near Belevedere and near Three Coconuts pass) were sampled, each with a native and nonnative pair, translating to eight transects of data collection (Table 1). Habitat assessments and photos were taken prior to data collection. A handheld GPS eTrex Venture HC unit was used to record coordinate positions. Plants that could not be identified in the field were
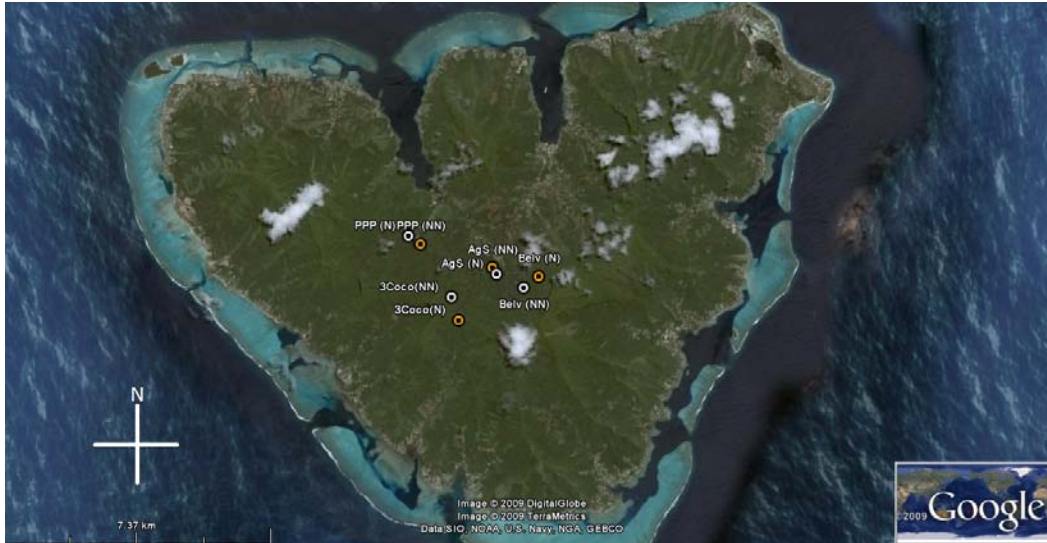
FIG. 1. Map of Mo'orea, French Polynesia with all paired study sites shown, retrieved on 10 December, 2009 from © 2009 Google Earth Pro. Image data retrieved from SIO, NOAA, U.S. Navy, NGA, and GEBCO. Image © 2009 DigitalGlobe, Image © 2009 TerraMetrics.

collected and placed in Ziploc bags for later identification at the Gump Stations.

At each site I assessed leaf litter and ground gastropods by placing a 15m random transect under chosen canopy cover. Quadrats, measuring 0.5m², were placed every 5m along the transect tape. Within each quadrat, every piece of leaf litter, stick, fallen log, and loose top soil were carefully inspected for living and dead gastropods. Specimens were collected with their substrate (unless substrate was large rock) in either gallon or quart-sized Ziploc bags and labeled. Shells were collected in microcentrifuge tubes and glass vials for protection during transportation. Preliminary field identifications were made and later reassessed in the lab at UC Berkeley Gump Station.

Lab analysis and observations

In the lab, collection bags were sorted through and morpho-species identifications were re-analyzed and re-recorded. The most abundant species were kept in separate Tupperware containers together with leaf litter and dirt for later behavioral and predator studies.

Specimen preservation

Voucher and Biocode specimens were preserved by drowning snails in water for 24 hours, followed by preservation in 70% ethanol, and stored in glass vials.

Escape time measurements

Terrestrial flatworms, known predators on land snails, were often found with snails in surveys (Sugiura 2008). *Platydemus manokwari* flatworms were introduced as biological control agents on *Achatina fulica* and threaten native populations of land snails such as *Partula sp*. (Cowie, 2006). The two most dominant species found in this study, Species A and Species B, were chosen for this experiment. Grid paper was smeared with flatworm secretions on the center of the page in a square measuring 8x8 cm. Snails were placed in the center of the square and their escape time out of the box of secretions was recorded. The procedure was repeated for controls without the secretions inside the box. The same snails were used for control trials. Ten trials for each control and treatment group of Species A and Species B were conducted (total of 40 timed escapes). A separate sheet of grid paper was used for each trial.

TABLE 1 Study sites with detailed descriptions

Study sites with elevations	Site Description	Weather Conditions	Notes
N1 (PPP) 17°31'40.80"S 149°51'19.50"W +/- 6m Elevation: 47m	*Hibiscus tiliaceus* dominated forest; Some *Cocos nucifera*; some sparse grass coverage of *Dypsis madagascariensis*; *Nephrolepis biserrata* within 60m of a stream.	Raining during collection.	Located in Amehiti Valley area in field with gate only open during day. The field will soon be cleared for pineapple plantations and adjacent field clearing had already begun from time of initial survey to data collection day.
NN1 (PPP) 17°31'47.50"S 149°51'9.00"W +/- 5m Elevation: 49m	*Falcataria moluccana* dominated canopy cover; *Wedelia sp.*, *Nephrolepis biserrata* (fern), *Poaceae sp.* (grass), *Zingiber sp.*; *Rhus taitensis* within visual range of site Within 60m of a stream.	Collection was made one day after a heavy rain.	Same notes as N1 (PPP).
NN2 (Ag School) 17°32'7.12"S 149°50'6.14"W +/- 5m Elevation: 96m	*Falcataria moluccana* dominated canopy cover; Invasive weed ground cover is highly pervasive at this site. *Poaceae sp.* (introduced grass), *Stachytarpheta sp.* (herbs with clusters of purple flowers), *Passiflora sp.* (passion flower vines) provide a thick, low shade coverage as the dominant ground cover. *Hibiscus tiliaceous* within visual range of site; within 60m of a stream.	Collections made on two days. Both days were sunny during collection; patches of sunlight filtering into site.	Located behind the Agriculture School, down the trail beginning at the pig barns, site marked with pink flagging tape.
N2 (Ag School) 17°32'12.40"S 149°50'2.50"W +/- 11m Elevation: 116m	*Hibiscus tiliaceus* dominated forest. There are also *Inocarpus fagifer* and *Syzygium malaccense* on site. Sparse grass coverage consisted of *Dypsis madagascariensis*, and *Zingiber sp.*; within 60m of a stream.	Collection was made two days after a heavy rain.	Located behind the Agriculture school, along the same path as NN2 but further down, entrance to site marked with pink flagging tape.
NN3 (Belvedere) 17°32'14.42"S 149°49'25.86"W +/- 13m Elevation: 225m	*Falcataria moluccana* dominated canopy cover. On a talus slope. *Myconia calvescens*, some vines of *Hibiscus sp.* Other vegetation within visual range: *Mikania micrantha*, *Davallia sp.*, *Cyclophyllum sp.*, *Lantana camara*, *Adenathera sp.*, *Rubis rosaefolius*, *Coffea sp.*, *Nephrolepis biserrata*	Sunny during collection with patches of sunlight filtering into site.	Located off the main road to the Belevedere about four switchbacks from Belevedere overlook, site entrance marked with pink flagging tape.
N3 (Belvedere) 17°32'23.70"S 149°49'38.90"W +/- 13m Elevation: 259m	Canopy cover predominately *Hibiscus tiliaceus* and *Neonauclea forsteri* as well as some *Inocarpus fagifer*. Some other vegetation within visual range of site includes: *Ficus* (Banyan tree), some *Myconia calvescens* (invasive plant) *Angiopterus* (giant fern), as are *Aleurites* (candlenut), and one *Artocarpus* (breadfruit).	Collections made on two separate days, one day was raining during collection; one day was a day after a heavy rain.	Located off the Trois Pinus trail along a bush-whacking trail (beginning at the large Banyon tree) marked with pink flagging tape, near a marae site mapped by Patrick Kirch.
NN4 (3 Coconuts) 17°32'31.50"S 149°50'41.30"W +/- 5m Elevation: 306m	*Falcataria moluccana* dominated canopy cover; *Poaceae sp.* and *Stachytarpheta sp.* were the main ground cover. Other vegetation in study site: *Myconia calvescens*, Casuarina sp., and one *Angiopterus sp.*	Collection was made three days after a heavy rain.	Located on the Three Coconuts trail, past the pass approximately 15 minutes, entrance to trail on right marked by pink flagging tape, entire trail marked off to *Falcataria moluccana* stand.
N4 (3 Coconuts) 17°32'50.30"S 149°50'35.00"W +/- 6m Elevation: 397m	*Hibiscus tiliaceus* dominated forest. The greatest ground coverage is *Freycinetia*. Other vegetation in visual range: *Myconia calvescens*, *Angiopterus sp.*	Collection was made one day after a heavy rain.	Located on the Three Coconuts trail, almost immediately after main pass, trail on left marked by pink flagging tape. Collection site marked by pink flagging tape.

Statistical analysis

Biodiversity study

All data were analyzed using the software JMP (8.0.1, SAS Institute 2009). Discriminant analysis was conducted on live species raw data, excluding rare species counts[*], with y-categories distinguishing between the four paired sites, native and nonnative sites, mid and low elevations using the parametric multivariate Wilks' Lambda test to determine if there was statistical significance in the species composition of the hypothesized parameters. The same discriminant analyses were conducted with dead species raw data. Wilcoxon tests were performed on the distribution of the two most predominant species separately. Distributions of Species A and Species B in native vs. nonnative and low vs. mid elevations were analyzed to assess their seemingly homogenous distributions.

Escape time measurements

All data were analyzed using Excel 2007 for Windows. Two-factor without replication ANOVA tests were used to compare control and treatment escape times.

RESULTS

Biodiversity study

All data were analyzed using parametric associated multivariate analyses with statistical software JMP (8.0.1, SAS Institute 2009).

Live specimens in study

Discriminant analysis of all data from live specimens (excluding rare species) categorized by sites (PPP, AgS, Belv, and 3coco) produced significant separation between sites (Wilks' Lambda, F=4.15, DF=33, p<0.0001) (Fig. 1).

Discriminant analysis of the same data was used to distinguish between native and nonnative quadrat counts, which produced

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[*] Rare species were described as a total of one individual found for all sites.

significant separation between the native and nonnative sites (Wilks' Lambda, F=2.91, DF=8, p=0.0299) (Fig. 2). Discriminant analysis of the same data using the categories of mid and low elevations also showed significant differences between categorizations (Wilks' Lambda, F=4.44, DF= 8, p=0.0047) (Fig. 3).

Species F and *Georissa sp.* were only found in native sites. The nonnative slug, *Vaginulus sp.*, and Species H, of the order Subulinidae, were only found in nonnative sites. Species F was only found at low elevations. *Georissa sp.* was only at mid elevations. Species H and *Vaginulus sp.* were not found at the highest of mid elevations. Species A and Species B tended to be distributed at all sites with some exceptions. Species B is not found in NN1 where Species H is found in high density and only one individual of Species A was found in the same site. The two most abundant species found in survey were analyzed separately. In general, total counts of Species A (117 individuals) were greater than Species B (66 individuals). Species B had no affinity for native or nonnative sites (Wilcoxon, ChiSquare=0.25, DF=1, p=0.6195) or for low or mid elevations (Wilcoxon, ChiSquare=2.54, DF=1, p=0.1109). Species A had no affinity for native or nonnative sites (Wilcoxon, ChiSquare=0.22, DF=1, p=0.6358), however, there were more Species A at lower elevations than at mid elevations (Wilcoxon, ChiSquare=5.12, DF=1, p=0.0236).

Empty shells in study

Discriminant analysis from all dead species data was conducted on site separation with a significant distinction between sites (Wilks' Lambda, F=2.47, DF=24, p=0.0045) (Fig. 4). Discriminant analysis was conducted on the same data with the distinction of categories between low and mid elevation sites, yielding a significant separation between sites (Wilks' Lambda, F=4.63, DF=8, p=0.0038) (Fig. 5). Discriminant analysis was conducted on the separation of quadrats based on native and nonnative sites, which yielded an insignificant separation between sites (Wilks' Lambda, F=2.00, DF=8, p=0.1093) (Fig. 6).
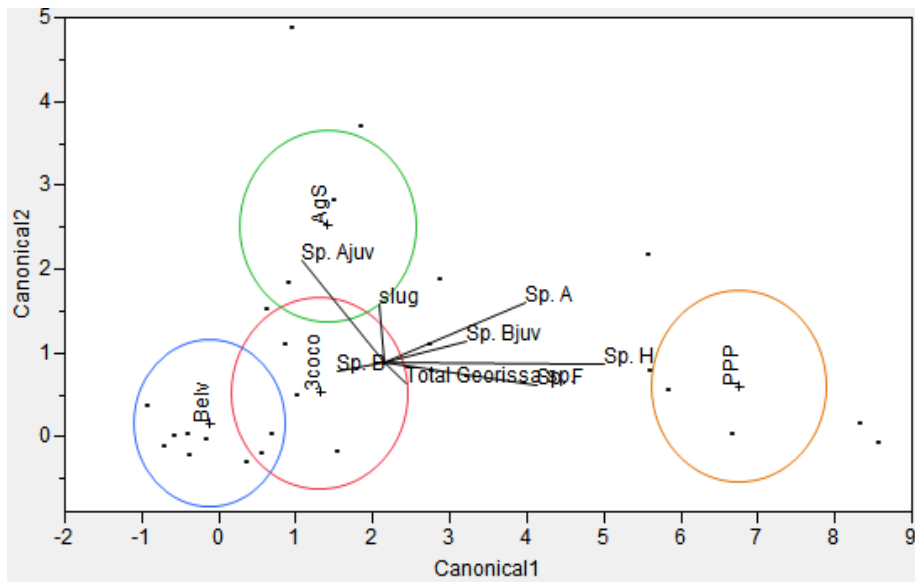
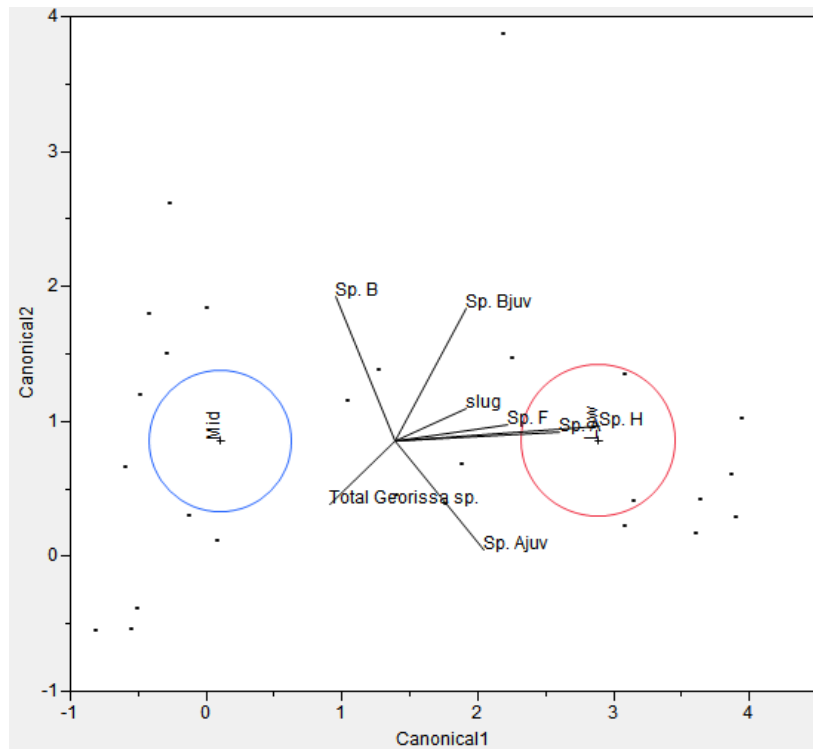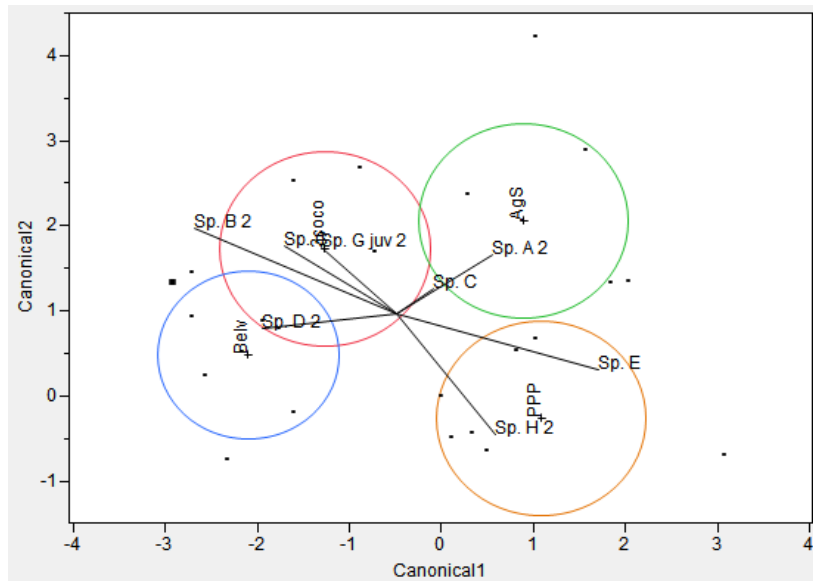**FIG. 1.** Discriminant analysis of live species abundances and absences for all quadrats of collection with categories distinguished by paired sites. This is a visual representation of the distinction between sites and which species were most responsible in this distinction. (Wilks' Lambda, F=4.15, DF=33, p<0.0001).
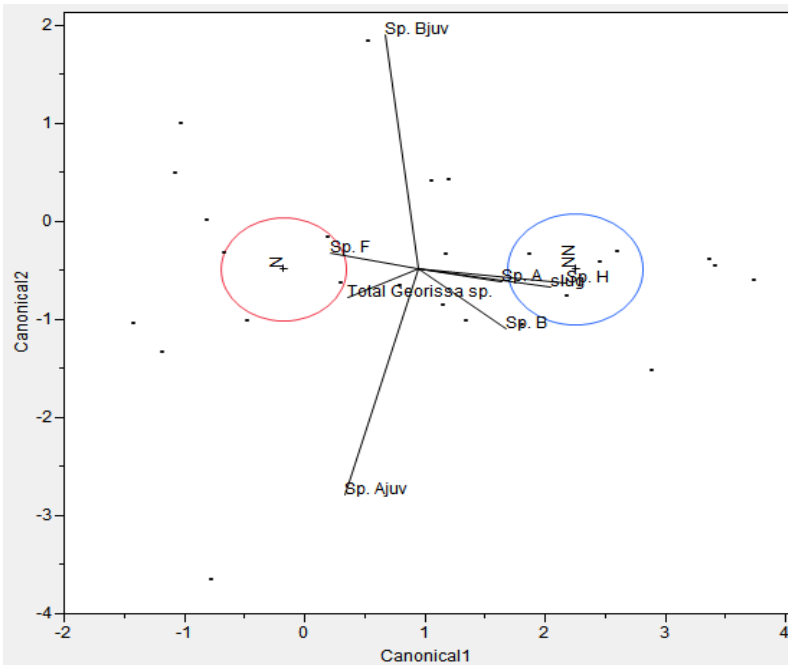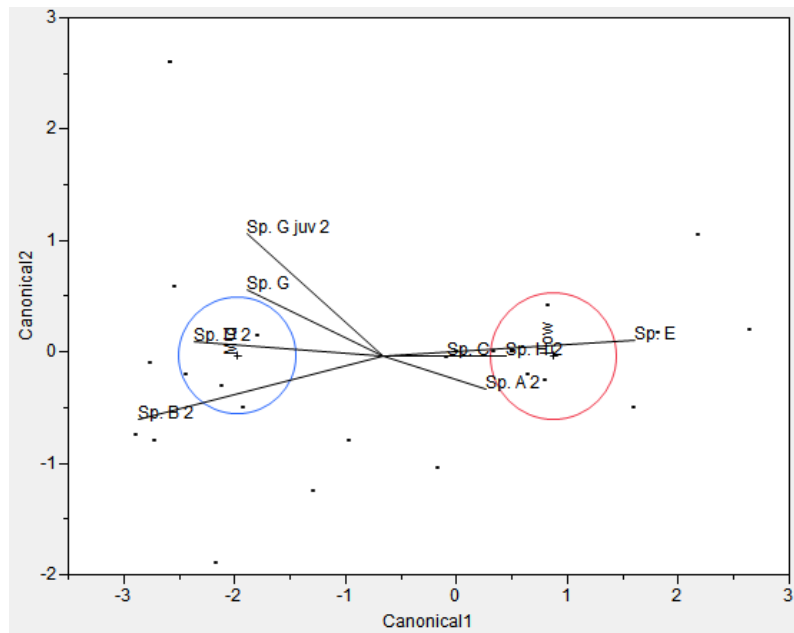

FIG. 2. Discriminant analysis of live species abundances and absences with discriminating categories designated as native (N) and nonnative (NN) sites. The direction of the lines illustrates which species had the most significant effect in separating these categories. Species F and *Georissa sp.* were only found in native sites as Species H and the slug were only found in nonnative sites. (Wilks' Lambda, F=2.91, DF=8, p=0.0299).
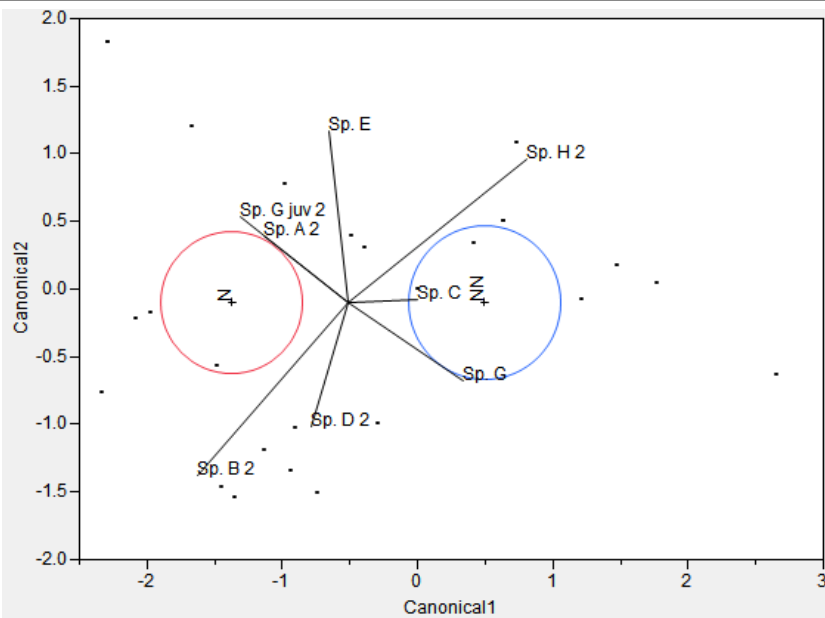
FIG. 3. Discriminant analysis of live species abundances and absences in all sites categorized by low elevations and mid elevations. The lines with species designations illustrate the influence each species had in affecting the spread of the data. *Georissa sp.* was only found at mid elevations and Species F and Species H were only found at low elevations. (Wilks' Lambda, F=4.44, DF= 8, p=0.0047)

FIG. 4. Discriminant analysis of dead species abundances and absences. This is a visual representation of the distinction between sites and which species were most responsible for this distinction. (Wilks' Lambda, F=2.47, DF=24, p=0.0045).

FIG. 5. Discriminant analysis illustrating dead species abundances and absences based on low and mid elevation categories. Species E was only found at low elevations. Species G juvenile was only found at mid elevations. (Wilks' Lambda, F=4.63, DF=8, p=0.0038).

FIG. 6. Discriminant analysis illustrating dead species abundances and absences based on the categorizations of native (N) and nonnative (NN) sites. Species C and Species G were only found in nonnative and Species G juvenile was only found in native. (Wilks' Lambda, F=2.00, DF=8, p=0.1093).
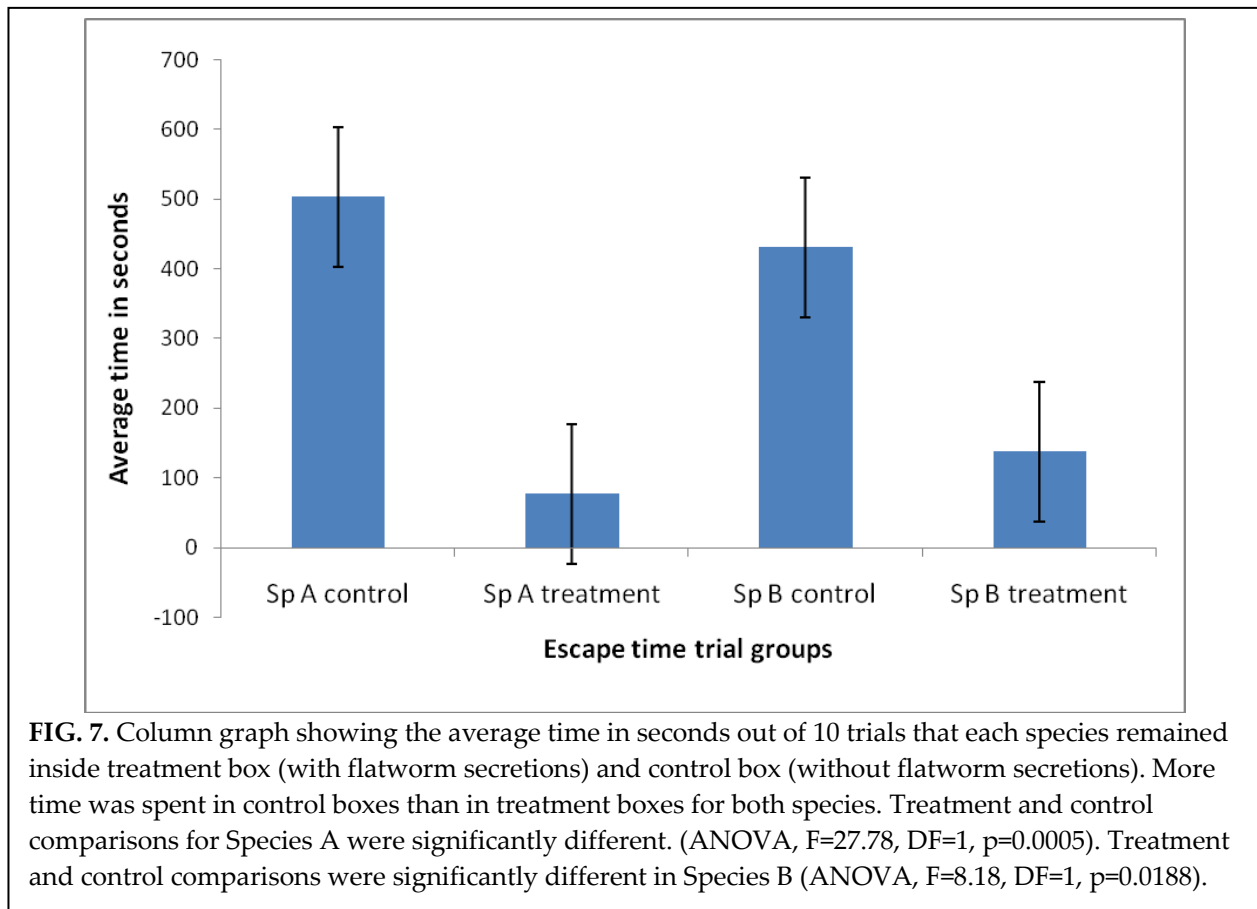
Treatment

Species A spent significantly less time in box when flatworm secretions were inside than when there were no secretions (ANOVA, F=27.78, DF=1, p=0.0005). Species B also spent significantly less time in the box when secretions were inside than when there were no secretions (ANOVA, F=8.18, DF=1, p=0.0188) (Fig. 7). Snails in treatment trials generally responded with one of two behaviors after being placed in the 8x8 cm box drawn on grid paper. One response involved a sinewy escape route from the box. The other response was a quick direct route out of the box. One anomalous response was complete fascination with the paper, where the snail used its radula to scrap at the paper for over 10 minutes.

Control

Species A and Species B both had similar responses to control. Two general behaviors were noted. The most common response was remaining stationary for over 10 minutes using their radula to scrap at the paper and the other response was a quick direct route out of the box.

FIG. 7. Column graph showing the average time in seconds out of 10 trials that each species remained inside treatment box (with flatworm secretions) and control box (without flatworm secretions). More time was spent in control boxes than in treatment boxes for both species. Treatment and control comparisons for Species A were significantly different. (ANOVA, F=27.78, DF=1, p=0.0005). Treatment and control comparisons were significantly different in Species B (ANOVA, F=8.18, DF=1, p=0.0188).

Biodiversity study

Live specimens in study

Habitat modification, including introduced plant species, influences the decline of native biota species (Cowie 2004). Clearing native forest leads to the spread of nonnative plant species, further reducing habitat for native species that are not adapted to the nonnative plants (Cowie 1998). *Georissa sp.*, a native to Mo'orea (Garrett 1884), was only found associated with native canopy cover. Likewise, Species F was only found associated with native canopy cover. This suggests that Species F is also a native species to Mo'orea.

A nonnative species would be expected to have either a homogenized distribution throughout native and nonnative forests, or would tend to favor the empty niche of the nonnative habitat. From the overall result of these data, the latter explanation appears most likely. The slug *Vaginulus sp.* and Species H (Order Subulinidae, most likely *Subulina octona*) are both recent introductions into French Polynesia (Cowie 2005) and are only found under nonnative canopy cover. Speculation presented by Cowie (2005) suggests that veronicellid slugs are inhibiting regeneration of native forests by eating plant seedlings, contributing to the spread and domination of nonnative canopy cover.

Low elevation areas typically represent recently introduced biota with native species tending to be restricted to higher elevations (Gillespie et al. 2008). The native species *Georissa sp.* (Garrett 1884), was only found in the higher elevation native sites. *Vaginulus sp.* and Species H were not present at the highest of the nonnative mid elevations (site NN4). Species F was only found at low elevations, but also only under native canopy cover. This could be an exception to typical trends. Perhaps, non-elevational factors are at work.

The two most abundant species, Species A and Species B (*Ovachlamys fulgens*), are distributed throughout all sites. These species clearly have the adaptive ability and generalist approach to succeed in both native and nonnative habitats. The presence of *O. fulgens* in French Polynesia has yet to be published outside of this research course (McNaughton 2007) and yet its distribution is homogenized over all sites, suggesting that it has had some time to spread. The successful colonization of *O. fulgens* is quite remarkable as its introduction presumably has been at least within the last 125 years, which is the time of the previous biodiversity study compiled of Mo'orean land snails and did not include this commonly found species (Garrett 1884). Knowing the precise date of introduction would lend great insight into the adaptive capabilities of this introduced species.

Because population densities are unknown from the past, previous diversity patterns cannot be used to compare the presumed spread of either of these species. Although Species A was not limited to native or nonnative sites, it was limited in elevation. Although there were individuals present in mid elevations, there were statistically more at lower elevations. Species A populations could still be in the process of increasing their elevational ranges and later studies could reveal a homogenization of Species A among elevations in addition to the currently observed homogenization of native and nonnative habitat.

The species composition at the lowest elevation nonnative site suggested that Species H was outcompeting Species A and Species B. Species A and Species B counts were unusually low at sites where Species H occurred. Species H is a member of the family Subulinidae, which are known to be introduced into French Polynesia (Cowie 2005). Competition between introduced and native snail species is well-documented (Byers 1999, Riley et al. 2008, Mooney and Cleland 2001, Cowie 2001). Interaction of two invasive snail species is difficult to locate; however, invasive species have been known to interact with each other both facilitating and inhibiting each other's invasion (Simberloff and Von Holle 1999). Species H occurred in high density in the soil, while Species A and Species B were typically on leaf litter or

grasses and small plants, so direct habitat competition is not wholly apparent.

The success of Species H as an introduced species could be attributed to certain behaviors. Species H had a noteworthy preventative method for desiccation: the snail retracts into its long spire shell and produces an air-filled mucous mass around the entrance to its shell. This species also appears to have a high tolerance for drowning. When drowning Species H before preservation, some individuals created a large mucous bubble surrounding the opening of their shell in a possible attempt to prevent drowning. These behaviors indicate biological preparation for the harshest of conditions, likely contributing to their role as a successful introduced species.

Empty shells in study

Unlike the live specimen data, shell data showed no significant difference between native and nonnative sites, yet elevations were still significantly different from one another. Shells could have been washed in by rain water from various sites skewing respective native and nonnative species composition. Also, some species like Species C and Species G were only found as shells, suggesting that they might be strictly arboreal species and that arboreal species might have different distributional patterns. This distinction has not been studied on Mo'orea and is not in the scope of this study. Future biodiversity studies of arboreal species, however, might still reveal discrimination between native and nonnative habitats.

Possible confounding variables during collection

Sites were chosen to the best of my ability, but there were possibly better representative sites that could have been selected. Native sites at lower elevations were commonly mixed with introduced species of vegetation. *Inocarpus fagifer* is a very well-established tree and was found in many locations of native and nonnative habitat. Some nonnative sites had more developed *Falcataria moluccana* canopy cover than others. Collections in the future should also be coordinated with the weather. Days after heavy rain would have been the preferable collection period, because there were noticeably more snails present. As it was, collections were made whenever it was possible.

Escape time trials

The effects of predatory chemical cues have been studied in freshwater snails (Turner et al. 2000), and chemical cues released by predators of terrestrial snails have been found to alter snail behavior (Lefcort 2006). For example, *P. manokwari* follows chemical cues in snail tracks up tree trunks to find its next meal (Sugiura and Yamaura 2008), but the detection of flatworms by their snail prey has not been investigated in the literature. A study conducted on *P. manokwari* reported the devastating effect of these predatory flatworms on land snails, driving many endemics to extinction (Sugiura and Yamaura 2008). Endemic land snail populations of Ogasawara islands have been in rapid decline since the introduction of *P. manokwari* (Sugiura and Yamaura 2008). A major concern now for Mo'orea should be the spread of these invasive predators and their impact on native land snails. A personal observation in the field with negative conservation implications is that flatworms were more frequently found at native sites compared to nonnative sites.

When the flatworm secretions were not present, both of the species stayed in the box for over 10 minutes (600 seconds) where they used their radula to rasp at the paper, in a presumed search for nutrients. Without the flatworm secretions on the paper they were content to explore their surroundings at a snail's pace.

For both Species A and Species B, a faster escape time was recorded for treatment groups compared to control groups. This result suggests that both of the species are able to detect the predatory flatworm's secretions. All of these species are introduced to the island (Species A is likely an introduced species) which raises the question: how do these introduced species from different backgrounds possess the ability to detect each other? The native range of *O. fulgens* is

thought to be on the Ryukyu islands (Stange 2006), while the native range of *P. manokwari* is New Guinea (Cowie 2006). The next step in this line of experimentation is to test species native to Mo'orea in these time trials to determine whether they can detect this introduced flatworm. Species A had faster escape times than Species B, which could be either indicative of a heightened awareness of the presence of the predator or simply faster velocity.

However, Species B, almost certainly *Ovachlamys fulgens*, as this is known informally as the "jumping snail" (Barrientos 1998, Barrientos 2000) and there is no comparable terrestrial snail movement, was recorded "jumping" with high speed video camera using Imaging Studio v2.5.6.0 software with 3.998 second Pre Trigger shot at 500 frames per second. This movement could help Species B to evade predators in the field as well and was observed once during the secretions trials.

Additional field observations

I climbed Rotui on Mo'orea in search of gastropods but I did not find any along the trail or at the summit. I searched on Motu Piti Uu Uta on Bora Bora for over an hour in all likely habitats for gastropods but I also did not find any. On Huahine I conducted a rapid habitat assessment in *Hibiscus tiliaceus* forest (S 16°46'23.5" W 151°02'13.8") for under an hour and found many Species F compared to a similar habitat in Mo'orea and only one Species A. If my assessments are correct and Species F is native to French Polynesia, then Huahine would represent a less disturbed community structure of gastropods. No flatworms or slugs were found in the search.

Future research

The field of terrestrial gastropods is poorly studied and much attention is needed (Cowie 2001). A much more thorough study on terrestrial gastropod biodiversity in leaf litter and in vegetation on Mo'orea is required as this current study is the most recent survey conducted since that of Garrett (1884) and a

more complete and updated list of species is required in order to begin conservation. The spread of invasive species throughout Mo'orea needs to be monitored, especially the spread of other invasive species, such as the predatory flatworms. Their populations should be compared to snail populations in the near future to assess their impact on land snail biodiversity.

Along with more biodiversity studies, most species on Mo'orea lack life history studies and diet assessments. Species H exhibits notable biology involving its mucus that requires further research. Species A also exhibited a behavioral response to unfavorable conditions, by releasing yellow air-filled mucus. This is another defensive behavior in snails that needs to be quantified. But one of the most amazing defensive behaviors was the jumping behavior exhibited by *O. fulgens*. The description of this behavior and biomechanics behind this extraordinary movement is a topic I will certainly be exploring in the near future.

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APPENDIX A
Pictures of specimens in study

Species A (Family Helicarionidae)

Species B (*Ovachlamys fulgens*)
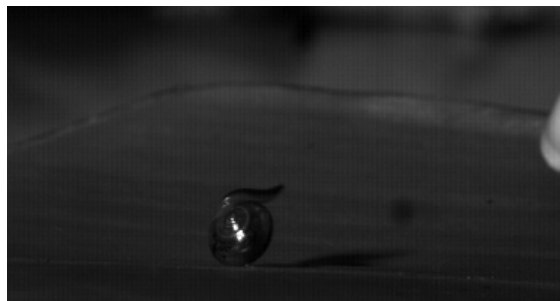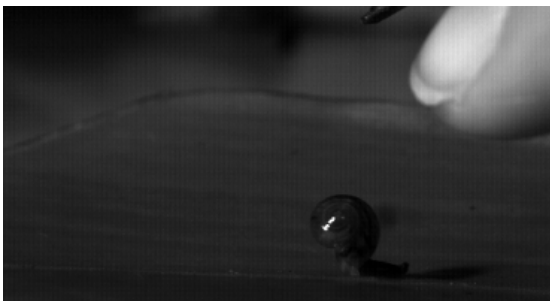
Species B – screen shots from high speed jumping video
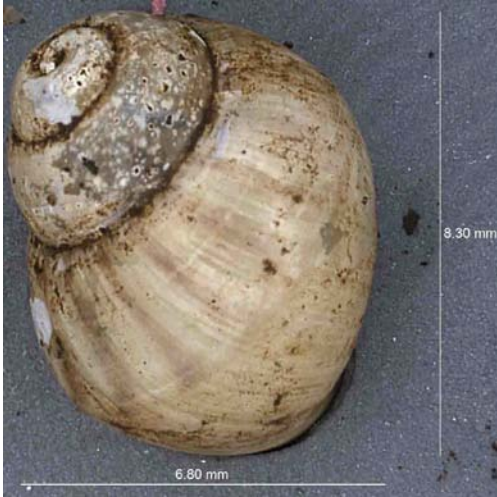
Species C – only found as shell
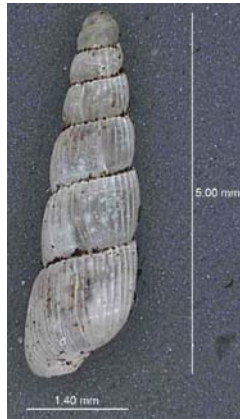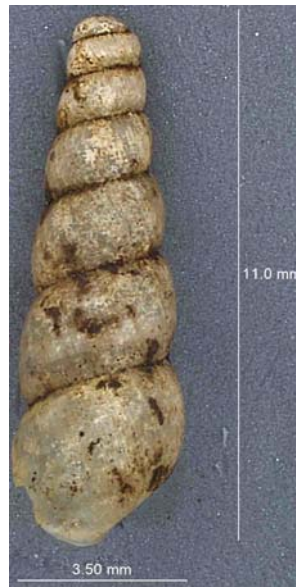

Species E – only found as a shell
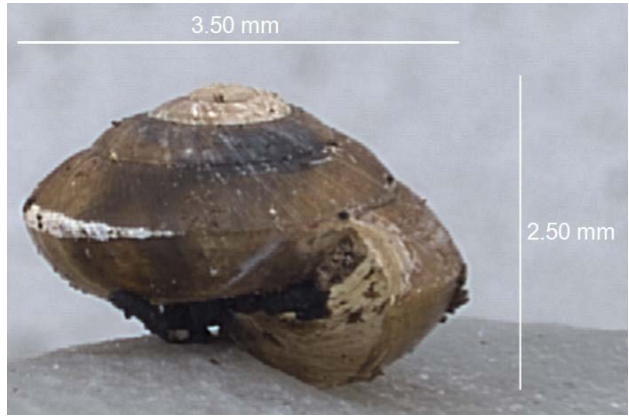
Species F

Species G – only found as a shell

Species G juvenile – rare as live, not used in
data analysis of live specimens

Species H - large specimen

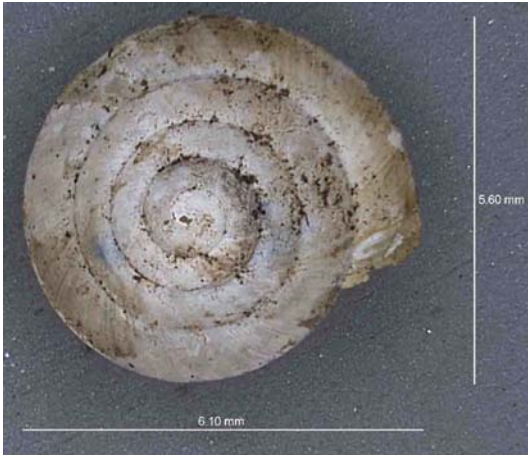Species H - small specimen

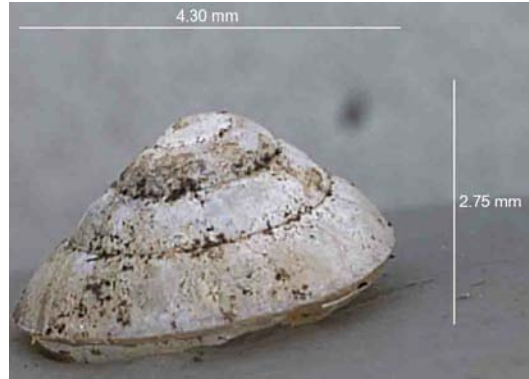Species H (morphotype 1)

Species H (morphotype 2)
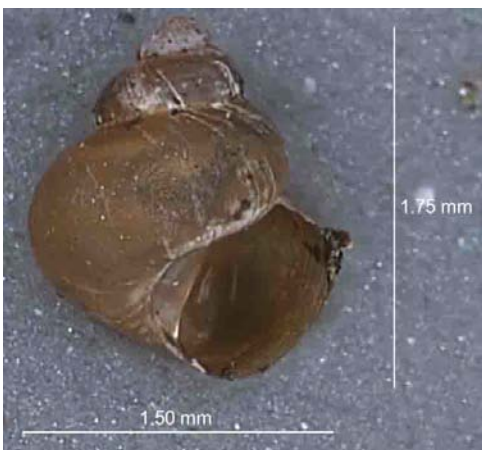

Species H (morphotype 1) exhibiting mucus behavior

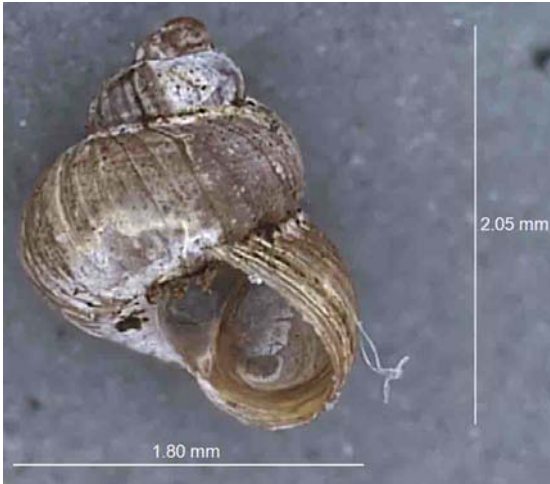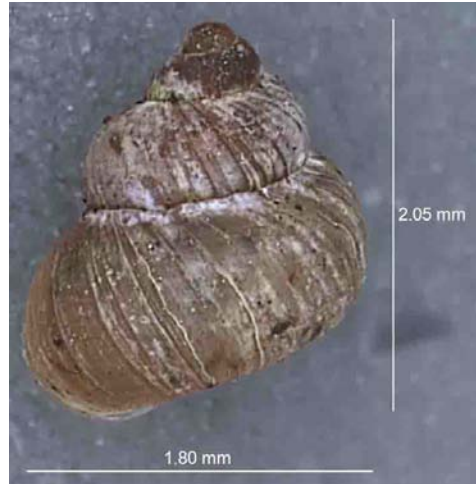Species H - small (morphotype 2)

Species K

Species L

Georissa parva
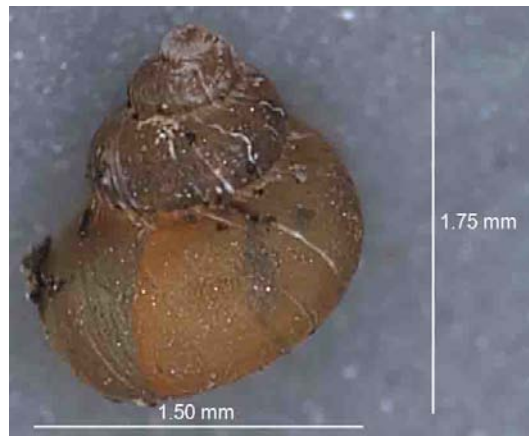
Georissa striata

Partula sp.

Vaginulus sp.