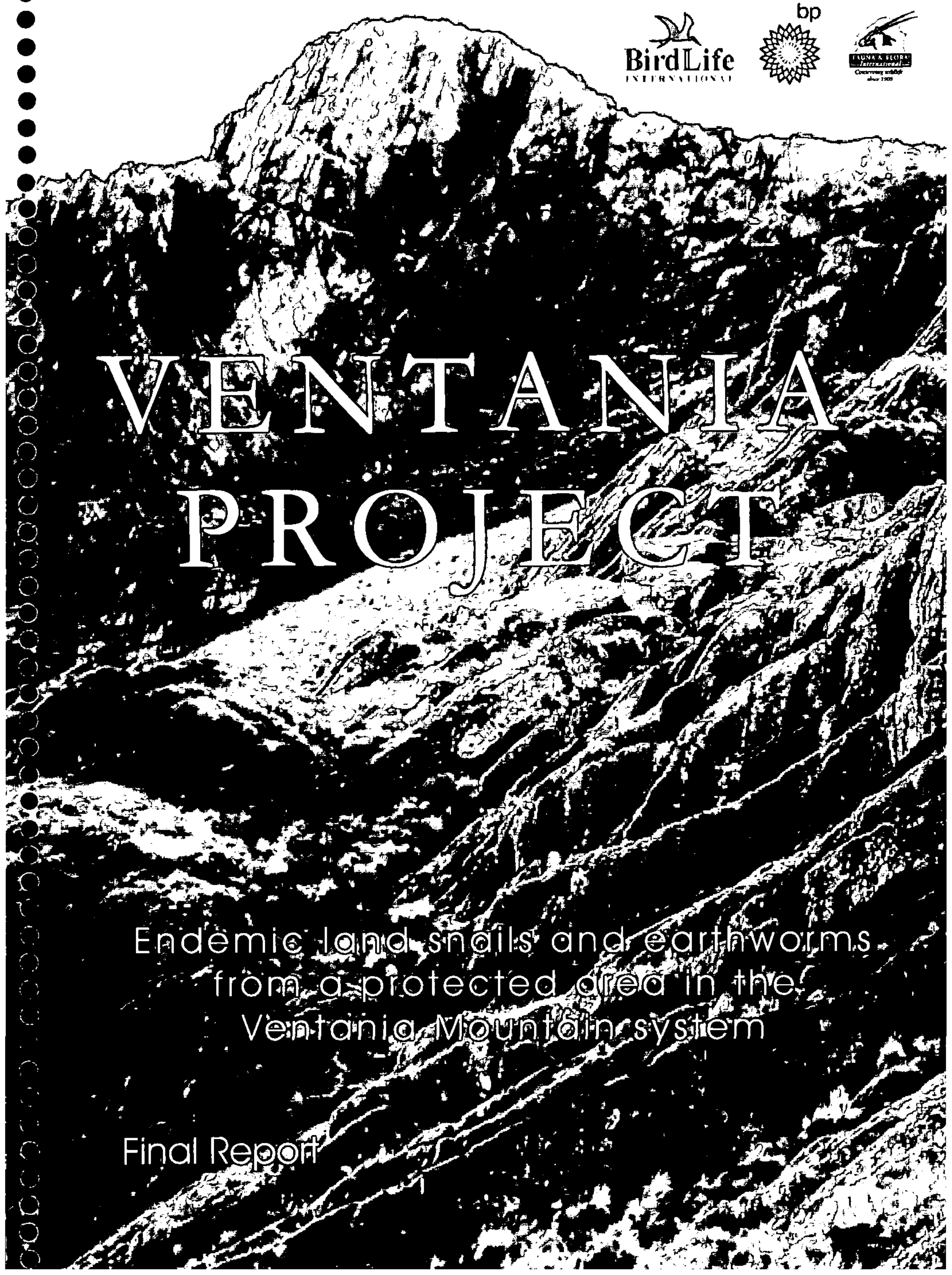
BP Conservation Programme 2002



VENTANIA PROJECT

Endemic land snails and earthworms from a protected area in the Ventania Mountain system

Final Report

VENTANIA PROJECT

Endemic land snails and earthworms from a protected area in the Ventania Mountain System

Bronze award winner

BP Conservation Programme 2002

With the collaboration and support of:

TELLUS – Asociación Conservacionista del Sur

FINAL REPORT

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1. SUMMARY

Introduction

The 'Ernesto Tornquist' Provincial Park, located at the Ventania Mountain System (Argentina), is the only reserve protecting the natural highland grasslands in southern Pampas. These ancient, Palaeozoic mountains are a remarkable outcrop in the Pampas plains; they have a diverse biota that contains many endemic species, including several land snails. This reserve is cause of concern due to the recognised impact of feral horses and the increasing area invaded by exotic woody plants. The effects of these disturbances on the natural vegetation and bird community dynamics have been already studied in this area, but invertebrates have been almost entirely neglected up to date.

There was a clear need of evaluating the impact of habitat loss and the conservation status of endemic land snails. Some of them could be endangered, though they are not included in the Red Data Lists due to the almost complete lack of studies on invertebrate ecology in the area. Land snails and earthworms have also conservation interest as part of the diet of endangered species and/or as indicators of soil disturbance.

This project aims to determine the status and population levels of the main land snail and earthworm species, and to identify key factors that determine their presence and abundance, paying particular attention to areas affected by disturbance that can affect the conservation objectives of this protected area.

Aim

To investigate the habitat, population levels and status of land snails, and to characterise the oligochaete fauna from the Ventania Mountain System, as a first approximation to future invertebrate conservation research.

Objectives

1) To identify places that have high diversity and/or abundance of species, and the key factors accounting for their habitat use, taking into account the impact of habitat loss and disturbances in order to sketch specific conservation strategies.
2) To determine the conservation status of some endemic snail species in order to assign them a proper conservation category.
3) To analyse the earthworm composition of soils within the 'Ernesto Tornquist' Provincial Park, in areas with and without disturbances, to check the state of a noticeable invasion by peregrine species.
4) To provide local museums, guides and conservation officers with material and information for education and control activities, such as ecological notes, distribution data, photographs and other related material.

Results and conclusions

Diversity of microsnails (shell diameter below 5 mm) was rather poor. By means of *in situ* searches in potentially suitable habitats –soil, litter, under stones, mosses- we found only two microsnail species. The probably introduced cosmopolitan *Paralaoma servilis* (Shuttleworth, 1852) -which was not formally cited for the Ventania mountains- occupies a wide range of microhabitats, in both natural and disturbed environments within the Park.

We have rediscovered, after forty years of no records, the endemic snail *Zilchogyra franzi* Weyrauch 1965, which was known so far by a single specimen. We have recorded only three locations with living specimens of this species, restricted to low insolated stone caves with moist soil and ferns. We also add information on its shell characteristics.

We studied the effect of environmental variables and horse impact on the four main autochthonous macrosnails: *Discoleus aguirrei* (Doering, 1884), *Plagiodontes patagonicus* (d'Orbigny, 1835), *Austroborus lutescens dorbignyi* (Doering, 1876) and the endemic *Ventania avellanedae* (Doering, 1881). We randomly established -in strata that ranged from summits to lowlands- 36 sampling areas where we selected two to five plots (total: 125 plots). We quantified snails and recorded environmental variables that included topography, habitat structure, vegetation physiognomy, edaphic factors, floristic composition and indexes of climate and horse impact. Data were analysed by means of corrected frequencies, chi-square tests, PCA and rank-order Spearman correlations. In general snail species co-occur. The most frequent is *Discoleus aguirrei*, followed by *Plagiodontes patagonicus*. Rocks seemed to be an important source of shelter; we have frequently found them under stones or in rock fissures and crevices, depending on the species. The highest snail densities were recorded in some summits of Sierra de la Ventana mountain range, usually associated to the endemic shrub *Grindelia ventanensis*. Chemical properties of the soil and local climatic conditions did not appear to be major determinants of land snail distribution. Horses might have a direct impact on snail species, affecting their distribution pattern, especially on *Austroborus lutescens dorbignyi* and *Plagiodontes patagonicus*. The impact of horses was greater in lowlands. In the Cordón Esmeralda mountain range, these land snails were frequent and abundant, probably due to a favourable structure and pattern of distribution of rocky outcrops, and to the absence of horses. Internal wire fences prevent horse entrance to this section of the Park; it is then advisable to warrant future horse exclusion from this area.

No living land snail populations were found in long term established pine stands. Pines have major effects changing the vegetation structure and the composition of soil and litter, clearly affecting autochthonous flora and fauna. There are many conservation arguments to stop the spread of pines, taking into account its drastic impact on natural environments. Persistence of land snail popultaions under pine canopy seems unlikely.

These four macrosnail species seem not to be endangered within the Park in the short term. However, if control activities on pines would cease, a long-term permanence of land snails -and of natural biota in general- in the Park is quite uncertain. Additionally, feral horse population is still growing, so the impact on land snails could rise in a near future.

Even if snail populations seem not to be endangered nowadays, a local decline of their populations in certain areas still could affect the population status of their natural predators. The possible causes of decline of *Prisitidactylus casuhatiensis* -endemic lizard, specialist predator of land snails, nowadays considered the most endangered reptile of Argentina- is discussed, and we warn of a possible indirect impact of a new invader of the Park –wild pigs- through its effect on local populations of snails.

We identified eight earthworm species. Most species recorded are exotic and peregrine: *Aporrectodea turgida, A. trapezoides, A. rosea, Octolasion tyrtaeum* and *Bimastos parvus* (family Lumbricids). We also found *Eukerria saltensis* and *Belladrilus jimi* (family Ocnerodrilidae), being South America a probable endemic area for this group. We recorded *Microscolex dubius* (family Acanthodrilidae), of probable patagonian origin.

The results were presented to local guides, conservation officers, and the community through a local NGO (TELLUS), and to the scientific community through congress presentations. Shells of land snails, a poster with photographs and a guide of land snail with information on their ecology and distribution were given to the Park's visitor centre.

2. STUDY SITE

The Ventania Mountain System

The ancient mountain system of Ventania is located within the southern district of Pampas grasslands (37°39' S to 38°17' S, 62° W; Buenos Aires province, Argentina), about 500 Km southwest of Buenos Aires city. It comprises several parallel mountain ranges arranged in a main NW-SE direction, with highest peaks of about 1200 m of altitude and slopes that can reach 70° in some SW mountainsides (fig. 2.1).

Climate is temperate; mean annual temperature is 14 °C. January is the hottest month and July the coldest, with mean temperatures of 18°C and 8°C, respectively. During summer, temperature can rise to 40°C, while winter temperatures can be as low as –10°C. Annual rainfall is around 800 mm, (slightly higher than in the surroundings plains) (Paoloni *et al.*, 1988), spring being the wetter season. There are occasional snowfalls during winter (Burgos, 1968).

The mountain system of Ventania was formed during Permian times by foldings of the Precambrian complex basement rocks, and Early to Late Paleozoic (Ordovician to Permian) cover sediments (von Gosen *et al.*, 1990). Sierra de la Ventana principally contains Devonic rocks of the 'Ventania' series, and Tertiary conglomerates in the lower section of the highest peaks (Harrington 1947, Suero 1972). Sections of the consolidated rock are covered by quaternary sediments that form a less than 2 m deep layer (Cappannini *et al.*, 1971). Soils are typical Argiudols, and litic Argiudols and Haplulodols (Frangi & Bottino, 1995).

The temperate Pampas grasslands deserve special conservation interest by the uniqueness of this habitat; it does possess neither a high biodiversity nor a high endemism value when considered as a whole, and especially when compared to eco-regions in northern Argentina. Nevertheless, within this area, the Ventania Mountains are highlighted as an 'outstanding biodiversity area' (Bertonatti & Corcuera 2000). The heterogeneity of habitats accounts for the high diversity of species of these mountains, considered as a unique 'biodiversity island' (Kristensen & Frangi, 1995). Two main habitat types occur in Sierra de la Ventana: soils and rocky outcrops in scattered units of diverse size and pattern (Kristensen & Frangi, 1996). Another important source of environmental variability is given by the interaction among topographic variables -altitude, slope, sun exposure- that determinates local climate variations ('mesoclimate'); substrate and vegetation, in turn, give rise to microclimatic variation. Therefore, a diverse flora and fauna thrives in the area, in spite of the existence of a single natural vegetation stratum (grasslands).

Phytogeographically, these low mountains lie in the 'Austral Pampean District' within the 'pampeana' phytogeographic province (Cabrera, 1976). Vegetation physiognomy corresponds to grassland, mainly dominated by Gramineae, like *Stipa*, *Piptochaetium* species, and Compositae; mosses, ferns and lichens are also abundant in rocky habitats (Frangi & Bottino, 1995; Long &

Grassini, 1997). The variety of ecological conditions allows the thriving of flora components belonging to different biogeographical regions; it has elements of the close 'espinal' phytogeographic province, as well as from the High Andes, Patagonia and Austro-Brazilian regions. This area has also many endemic plants; Long & Grassini (1997) listed 40 endemic species, subspecies and varieties.

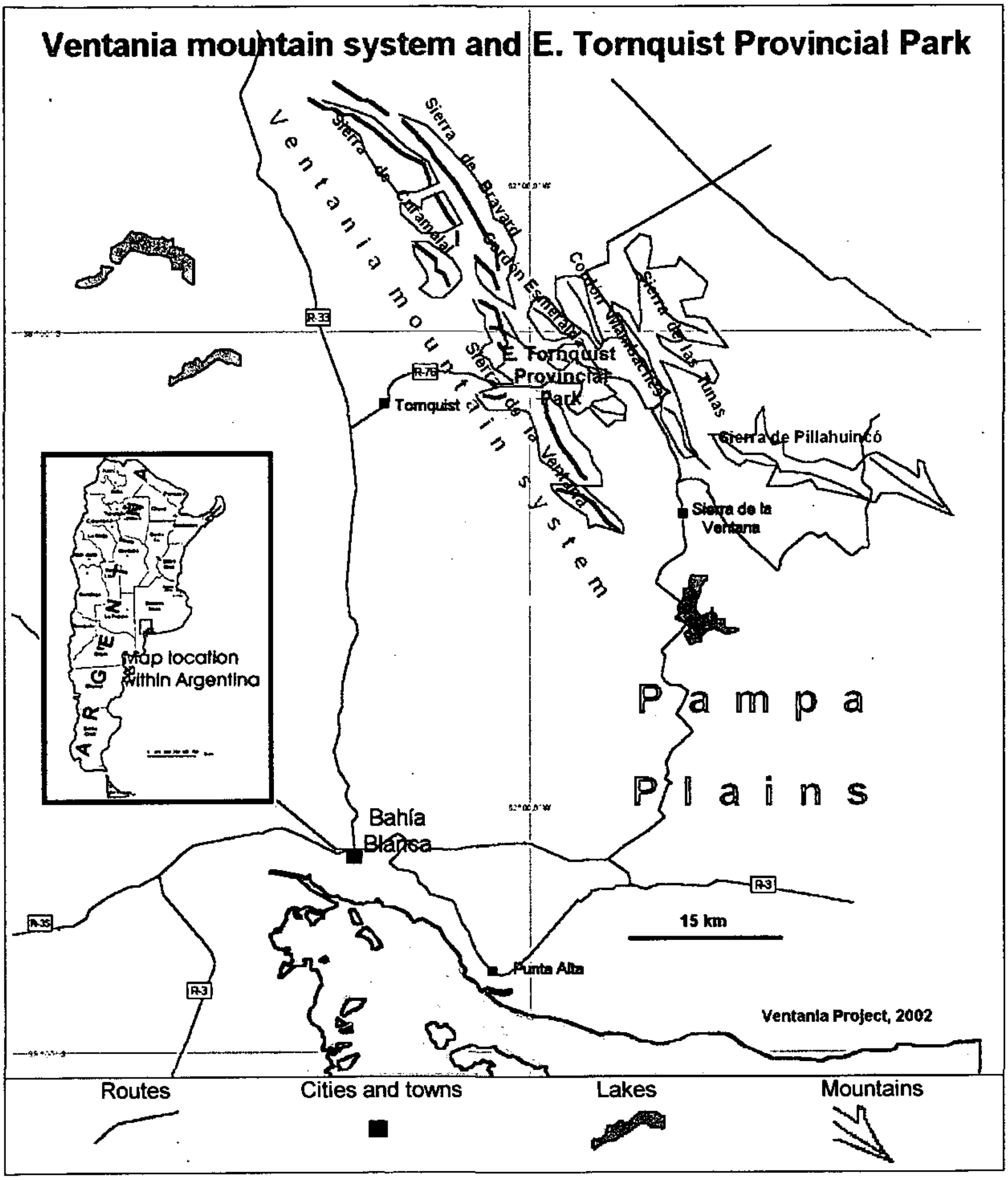
The fauna is also a combination of species from diverse regions (pampean, patagonic and espinal regions), with some endemic species. There are two endemic reptile species, the snake *Lyophis elegantissima* and the critically endangered lizard *Pristidactylus casuhatiensis* (Lavilla *et al.*, 2000), which feeds mainly on the land snail *Plagiodontes patagonicus* (Cei, 1993), and two endemic mammals, a rodent (*Phyllotis bonariensis*) and a marsupial (*Thylamys bruchi*). The Park contains also one of the last guanaco (*Lama guanicoe*) populations in the Pampas region.

Except for ants, whose diversity was recently assessed in the Park (Rodriguez Rey & Zalba, 2003), invertebrates are scarcely known. There are some endemic species, such as the scorpion *Bothriurus voyati* (Bothriuridae) (Maury, 1973), and some strictly endemic land snails: *Ventania avellanedae*, *Plagiodontes rocae* (Orthalicidae, Odontostominae), *Zilchogyra franzi* (Endodontoidea, Helicodiscidae). Other land snail species are shared with the surrounding plains or other mountain systems nearby. Additionally, some endemic taxa of daddy long legs (Ringuelet, 1961), hairworms and springtails are known in the Park. More studies in this area would certainly reveal other endemic, still undiscovered taxa.

Although the Pampas is the most densely populated and modified ecosystem in Argentina (Bertonatti & Corcuera, 2000), the Ventania Mountains have received a relatively less human impact than the plain Pampas due to the rocky outcrops that difficult an intensive agricultural use. This does not mean, however, that the mountains are a pristine, undisturbed habitat. The mountains face clear conservation problems. Main threats to this environment are the impact of introduced herbivores (cattle), and invasions of exotic plants, especially trees, a component that is virtually absent from the natural flora.

Conservation of grassland habitats from temperate regions has received historically less attention than other natural habitats with a higher biological diversity, *e.g.* rainforests. This is highlighted by the fact that there is only a single, small area protected for the conservation of natural grasslands: the 'Ernesto Tornquist' Provincial Park.

Figure 2.1


Ventania mountain system and E. Tornquist Provincial Park
Ventania mountain system
Sierra de Curamalal
Sierra de Bravard
Cordón Esmeralda
Cordón Chaco
Sierra de las Tunas
E. Tornquist Provincial Park
Sierra de la Ventana
Sierra de Pillahuincó
Tornquist
Sierra de la Ventana
R-33
R-76
R-3
R-35
Map location within Argentina
Pampa Plains
Bahía Blanca
Punta Alta
15 km
Ventania Project, 2002
Routes
Cities and towns
Lakes
Mountains

The 'Ernesto Tornquist' Provincial Park

This Park was created in 1937, on the basis of a donation and sale of lands by Mr Martín Tornquist to the Buenos Aires province Government. Three years later, further expropriation of neighbouring lands expanded the Park to its present surface of 67 km^2.

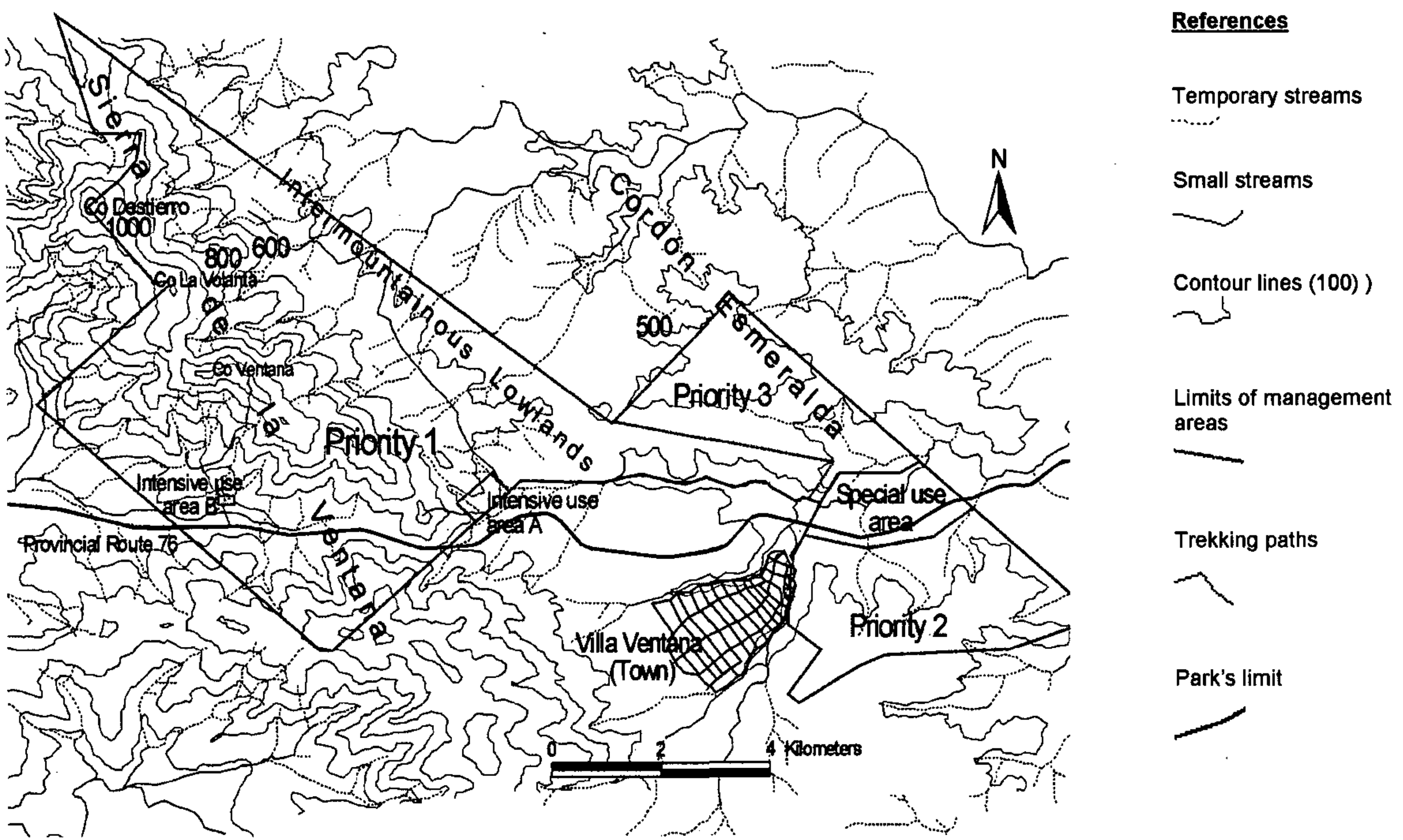
The reserve is located in the central zone of Sierra de la Ventana, the main mountain range of the Ventania Mountain System. It also includes a part of Cordón Esmeralda, a lower mountain range, and a section of the inter-mountainous lowlands lying between them (fig. 2.1 and 2.2). The highest peaks of the Park are, from north to south, Cerro Destierro (1172 m), Cerro La Volanta (1100 m) and Cerro Ventana (1134 m). These are also the highest peaks of the whole system, save Cerro Napostá (1110 m) and Cerro Tres Picos (1239 m), which are located farther south.

The Park is a popular destination for local tourism; the commonest hiking is climbing up to the 'hueco de la Ventana' -a natural, huge hole in the rocks, resembling a window (= 'ventana')- at the summit of Cerro Ventana. More information about tourist activities in the Park can be seen on the attached leaflet (attachment 9). Tourist activities provide an excellent opportunity to get in touch with the community for conservation education work. These activities are part of the conservation education programme of the Park (PEA: 'Programa de educación ambiental') carried out by specialised guides under the direction of Park rangers. The programme has a wide audience: tourists (mostly family groups), as well as students and teachers in programmed cultural visits. Other education source is the visitor's centre, a didactic room that exhibits photos, materials and information on geology and biodiversity of these mountains. More information about the education programme of the Park is in page 12 and in the leaflet about the Education Conservation Programme (attachment 10).

The Provincial Route # 76, which crosses the southern area of the Park, is the main communication way to neighbouring towns. It (factually) splits Sierra de la Ventana and Cordón Esmeralda mountain ranges into a northern and southern section. The small section of Sierra de la Ventana, south of the route, has received little attention because none of the customary tourist attractions lies within its limits, which are not physically defined. Additionally, a part of this land portion is under legal quarrel between the Park and a neighbouring ranch. As a consequence, land use has been erratic over most of the Park, *e.g.* sometimes the land was rented out for cattle pasturing or other uses such as hunting ground.

The fundamental objective of the Park is conserving the typical biodiversity of the highland Pampas grasslands (Fiori *et al.*, 1997), though two biological invasions severely affect the completion of this goal: introduced woody plants and feral horses. Effective control action is urgently needed to avoid even worse consequences.

Figure 2.2 Ernesto Tornquist Provincial Park



A Management Plan for the Park

Researchers from Universidad Nacional del Sur (Bahía Blanca city) and Universidad Nacional de La Plata (La Plata city) have performed many conservation-oriented studies along several years, but a management plan is still necessary for coordinating and getting a compact to develop down-to-earth management policies.

Several specialists with different academic skills collectively wrote a Management Plan in 1997, during a series of meetings organised and coordinated by the GEKKO group (Conservation Studies Group, UNS). As a result, management categories were defined according to the Provincial Law #10.907 of Reserves and Natural Parks, along with previously established objectives that included not only biodiversity conservation goals, but also geological, cultural and touristic issues. The area was divided into three categories according to priority for immediate conservation activities: 1st, Sierra de la Ventana; 2nd, Cordón Esmeralda, south of the route; and 3rd, Cordón Esmeralda, north of the route (fig 2.2). Further divisions include the 'Intensive use area' (administration sector and control area for trekking tourist activities) and a 'Special use area', for productive activities of low environmental impact (Fiori *et al.*, 1997). We include here a brief description of their habitats, which will be used to a later discussion of snail distribution according to this areal division.


'Cerro Ventana', 1134 m, Sierra de la Ventana, from its steepy SW slopes.

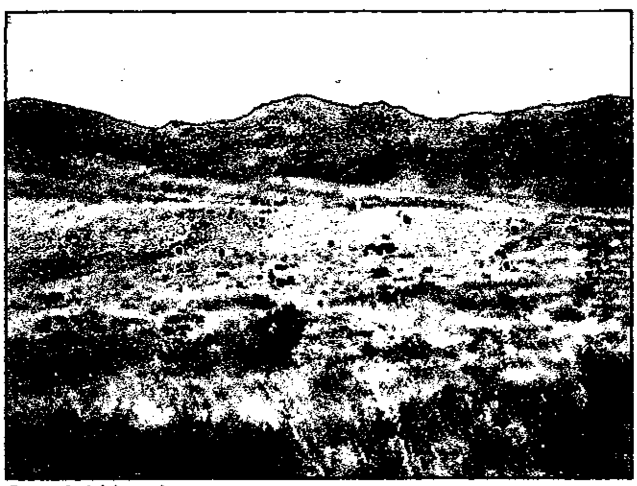
Priority 1 Area: It is the main area of the Park, including Sierra de la Ventana mountain range (the highest peaks), a small portion of Cordón Esmeralda mountain range, as well as the intermountainous lowlands. Therefore, it has the greatest environmental diversity: gorges, summits, valleys and lowlands. Rocky outcrops have various geological origins. Horses are found mainly in the lowlands and in NE-oriented slopes of the mountains; however they are found even at summits, and they are almost absent from the portion located south of the route.

Priority 2 Area: This area covers the southern part of Cordón Esmeralda (south of the route). Habitat description is presented in the next section (Priority 3 Area).

Priority 3 Area: This area comprises a considerable section of Cordón Esmeralda mountain range, north of the route. Cordón Esmeralda consists in a group of gentle-slope hills, lower than the main Sierra de la Ventana mountain range. Moderate slopes dominate the landscape; there are no gorges or summits, which are common in Sierra de la Ventana. From a geological viewpoint, Cordón Esmeralda belongs to the formation Lolén, with typical schistose rocky outcrops interspersed with soil. Horse entrance is currently prevented by wire-fences, so they are virtually absent from the area, but one cannot discard previous horse presence in times when the Park lacked a clear management policy. There are no tourist activities in Cordón Esmeralda.

View of the small hills of Cordón Esmeralda.

Special Use Area: This area corresponds to the plain lowlands, located between both sections of Cordón Esmeralda (N and S of the route). This area, less than 300 has, is reserved for agricultural activities of low environmental impact (cattle). This is a highly modified environment with deep soils free of rocks.



Special Use Area, cows.

Intensive Use Areas: These are two geographically disjunct forested and highly modified areas, reserved for human activities. Area A (fig. 2.2) comprises the Park's administration office, the small museum, a centre for tourists and base for some trekking, houses (*e.g.* Park rangers), and rooms for tourist guides and researchers. This is a typical anthropically modified environment. Area B is a base for trekking activities and the place where registration cows of tourists is done.


Intensive Use Area: Base of Cerro Ventana. Reception of tourists.

Primitive area: Tourist paths for trekking (fig 2.2).

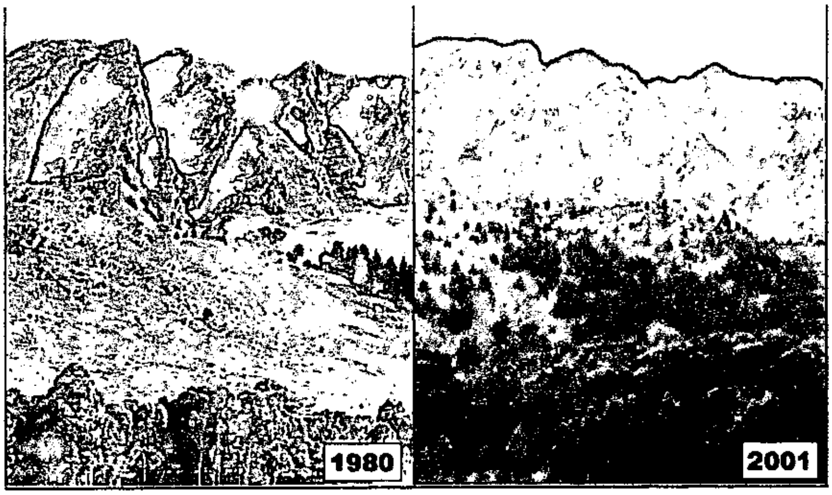
Pines: a conservation problem

Before the modern settlements of humans, there were no trees in the area, except for some occasional specimens of caldén (*Prosopis caldenia*) and sauce colorado (*Salix humboldtiana*), of restricted distribution.

Among the many woody plants that were intentionally introduced into the Park, there are two pine species (*Pinus halepensis* and *P. radiata*) that represent the main threat to biodiversity, due to their wide distribution and spreading rate. Some pinewoods increased their area up to ten times during the last 25 years (Zalba, 1997). Pines affect nowadays mostly the SW slopes of Sierra de la Ventana, as a consequence of the growth and spreading of some forests that were initially implanted near the route.


Pine spread on SW slopes of Sierra de la Ventana in the 'Ernesto Tornquist' Park

Primary effects of pines are sun radiation reduction, soil acidification and other profound alterations of soil properties (Amiotti *et al.*, 2000). These changes cause a replacement of natural grasses -unable to live under pine canopy- by exotic plants, and lead to a deep modification of soil biota, causing a noticeable reduction and fragmentation of natural habitats. The presence of pines also causes negative consequences on the natural avifauna and plant communities (Zalba 2000, 2001).

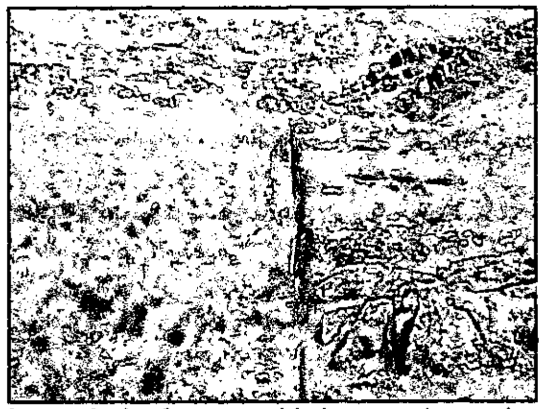


Pine spread in twenty years.

The GEKKO group carries out mechanical control of pines on populations located on NE slopes of Sierra de la Ventana, within the Park. The preliminary monitoring process reveals a successful grassland recovery (Zalba *et al.*, 2002). Pine populations on the SW slopes are dense and cover such an extensive area that a complete mechanical eradication seems impossible. Therefore, this area is perhaps definitely lost, at least for medium-term management. Nevertheless, a control programme should be performed on these populations to avoid further spread. Notwithstanding, such an extensive control plan presently faces a possible rejection from the local community, which is particularly fond of trees and in general uninformed about local conservation issues.

Feral horses

Some exotic vertebrates thrive in the Park, *e.g.,* feral pigs, feral horses, cows and Dama deers (*Dama dama*). Feral horse population was originated from five individuals released in 1942. By 1997 population number was estimated to be of about 500 individuals in an area of *ca.* 2000 has -the highest density of introduced feral horses in a reserve in the world (Scorolli, pers. com.)- and they are still growing in numbers (Scorolli, 1999). This is the animal invader with the greatest impact on the Park.


Internal wire fence avoids horse entrance in the left section.

Internal wire-fences, the Provincial Route 76, and habitat characteristics shape the distribution pattern of horses. They are more abundant in the main Park section, north of the route, especially on NE slopes of Sierra de la Ventana Mountains and in lowlands, where they reach their highest densities. Horses prefer the grasses located at low altitude inside the Park; nevertheless, they can be seen almost everywhere, even at summits. Southwestern slopes of Sierra de la Ventana, which does not provide a permanent water source, and Cordón Esmeralda mountain range, which is isolated by internal wire-fences, are less populated by horses than the NE slopes of Sierra de la Ventana (Scorolli, pers. com.).

Feral horses cause modifications in vegetation (composition changes and reduction of grass height), in soil properties (compaction, erosion and soil losses), and in rocks (release and breaking), thus having a direct impact on soil biota, including earthworms and land snails. Feral horses are known to affect local flora and fauna (Zalba & Cozzani, 2004; Long & Grassini, 1997). Control action is not currently carried out, as it should need a previous overcome of methodological, logistic and social obstacles.

Grazing is prevented in a minor fraction of the lowlands by means of a wire-fence exclosure set up in 1995. The great effect of grazing on vegetation height is abundantly clear when we compare the low grass carpet prevailing in lowlands -most vegetation belongs to the 0-15 cm stratum - with the high height grasses found in exclosures and most vegetation cover exceeding the height of 30 cm (Zalba & Cozzani, 2004).

The Park's 'Environmental Education Programme'

The objectives of this programme are to inform and raise awareness of the community of nature conservation problems, especially those faced by the 'Ernesto Tornquist' Provincial Park, and also to promote croncrete actions for nature conservation. This is carried out by a group of ten specialized guides, under the coordination of Park rangers. This programme is directed to a wide audience, but with a clear focus in promoting conservation education in children. The Park receives yearly the visit of hundreds of schools. The activities in the Park are intended to complement the theory seen in class, putting the children directly in contact with nature and its problems. Another activity of this group is the guidance of tourists in some paths, which provides another excellent opportunity to get in touch with the community for conservation education.

3. LAND SNAIL DIVERSITY

Land snail fauna in the Pampas region is known to be relatively poor, even when compared with the surrounding 'espinal' phytogeographical region, mostly covered by shrub lands (Parodiz, 1944, 1946a, 1946b). But, as opposed to the surrounding plains, the mountainous region of Ventania shows a relatively high species richness (Parodiz, 1946b), snail densities, and some endemic land snail species: *Plagiodontes rocae* Doering 1881, *Ventania avellanedae* (Doering 1881) and *Zilchogyra franzi* Weyrauch, 1965. Moreover, it represents the southernmost distribution limit of some families and subfamilies: Strophocheilidae, Odontostominae and -save for a single species- Bulimulinae, a fact that highlights the value of the Ventania system as a land snail shelter.

Knowledge on the malacofauna of Sierra de la Ventana started on with some early expeditions (19^{th} Century: Doering; Holmberg), with little subsequent research at the area, except for some taxon-based revisions (*e.g.* Parodiz 1946b, 1947; Fernández 1969, 1970; Breure 1978; Miquel, 1998; Pizá & Cazzaniga, 2003; Cazzaniga, Pizá & Ghezzi, in press; Pizá, Ghezzi & Cazzaniga, submitted). There is a significant gap of information regarding the smaller species[1], such as the Endodontoidea superfamily.

In this section we introduce an overview of land snail systematic and diversity in the Ventania Mountain System -focused primarily on the 'Ernesto Tornquist' Provincial Park- based upon bibliography and our own observations.

MICROSNAILS

A detailed account of microsnails in Sierra de la Ventana was never carried out. The naturalists Doering in the XIX century, and Holmberg and Parodiz in the XX century visited the mountains, but none of them reported microsnails species, except for *Succinea* species.

Microsnails are found on specific microhabitats. Therefore, they were usually overseen, the greater-sized species being much better known (Hylton Scott, 1957a; Solem, 1976). Effort directed specifically on taxonomy of microsnails in Argentina began in the 1950's, with the pioneering work of Hylton Scott and Weyrauch. Since then, many new species were discovered and described, most of them from northern Argentina and the Patagonian Andes.

Since most of the microsnails from Argentina are only known from shell descriptions, higher taxonomic placements -*e.g.* family level, which requires

[1] We use the term **microsnails** (opposed to **macrosnails**) to refer to the smallest land snails (usually less than 5 mm of shell diameter). Such size-based division is a useful classification, for small-sized shells are more difficult to found than macrosnails, due to their small size. Therefore sampling techniques for macro- and micro-snails differ; microsnails are usually searched in the laboratory after removal of potentially suitable microhabitats (soil, litter).

internal anatomic data- remains unclear for most of the Endodontoidea. In a recent preliminary effort of classification Fonseca & Thomé (1993, 2000) place the South American genera of the Endodontoidea superfamily into the families Charopidae, Helicodiscidae and Punctidae.

At the time we began our study, the endemic species *Zilchogyra franzi* Weyrauch, 1965 (Endodontoidea, Helicodiscidae) was the only microsnail species formally cited for the Ventania system (Weyrauch, 1965); this species was known only for a single specimen -the holotype- deposited at the snail collection of the Miguel Lillo Institute (Tucumán city).

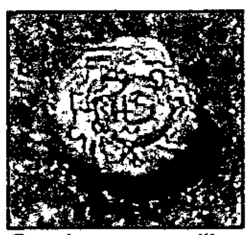
Two other species were likely to occur in the area: Weyrauch (1965) cited a certain *Radiodiscus argentinus* as co-occurring with *Z. franzi*, but to the best of our knowledge, this is a *nomen nudum*, because a description of this species was never published. Fernández (1973) also catalogued a museum set of *Radiodiscus pilsbryi* Hylton Scott 1957 (=*Paralaoma servilis* (Shuttleworth, 1852) (Hausdorf, 2001)) labelled as coming from Sierra de la Ventana, although this locality was not informed in the rest of the literature. Any findings of microsnails were therefore of interest.

Microsnails were searched during field trips, by *in situ* inspection of soil, mosses, litter, plants, rock caves, and under stones and dung. We recorded habitat type and geographical coordinates with the aid of a hand-held GPS, to facilitate future collecting of specimens for anatomical and histological examination. Collected shells were deposited in our snail collection (Laboratorio de Invertebrados 1, UNS). For snail identification we followed the studies of Hylton Scott (1957a, b) and Weyrauch (1965). We compared the collected shells with materials in the snail collection of the Miguel Lillo Institute (Tucumán city).

Microsnail diversity

1) *Paralaoma servilis* (Shuttleworth, 1852)
Familiy PUNCTIDAE

Distribution: This is a cosmopolitan species; it is found in all continents, except Antartica. *Paralaoma servilis* might be original from Australia and New Zealand, since other *Paralaoma* species are restricted to this area (Hausdorf, 2001), so this species was probably introduced into Argentina, as it was into many regions of the world.



Paralaoma servilis

Several species originally described as indigenous dropped into the synonymy of *Paralaoma servilis* (Shuttlesworth, 1852), particularly in Argentina, this is the case for species *Radiodiscus pilsbryi* Hylton-Scott 1957, *Radiodiscus misionensis* Hylton Scott 1957, and *Zilchogyra cleliae* Weyrauch, 1965 (Hausdorf, 2001).

2) ***Zilchogyra franzi*** Weyrauch, 1965

Family **Helicodiscidae**

Description: The shell, 5 mm in diameter of less, is flat, discoidal, with numerous ribs in its surface. It has a bright brown colour. The original description was made in terms of the shell characters of a single specimen (Weyrauch, 1965). We found some shells that fit well with the description of Weyrauch; other specimens were larger. Table 3.1 shows the natural variabilty of these shells according to our data.


Zilchogyra franzi
(diameter = 5 mm)

Table 3.1 Shell measurements (in mm) of *Zilchogyra franzi*. Bold: holotype's dimensions (Weyrauch, 1965).

Shell		Aperture	
Max. Diameter	Height	Height	Width
3,7	**1,7**	**1,3**	**1,1**
2,6	1,1	1,2	1,0
3,7	1,4	1,3	1,3
4,0	1,5	1,4	1,4
5,2	2,4	1,7	1,7
5,2	2,1	1,8	1,8

Distribution: This species, endemic to Sierra de la Ventana, was described by Weyrauch (1965) and never found again until our project. Details on the rediscovery of *Zilchogyra franzi* are at *Eslabón 13* (newsletter of TELLUS: Asociación Conservacionista del Sur, see attachment 4).

A comment on '*Radiodiscus argentinus*'

Weyrauch (1965) stated that the single shell of *Zilchogyra franzi* Weyrauch 1965 was found together with '*Radiodiscus argentinus* Weyrauch' but he never published a description of this alleged new species. While revising the personal notes that Weyrauch left at the Instituto Miguel Lillo in Tucumán, where he worked until his death, we found an unpublished description of *Radiodiscus argentinus*, and an indications of the reasons for not publishing it: the only shell he has got was juvenile ('1 Ex. juv.; ohne ein erwachsenes Gehäuse nicht zu beschreiben'). Anyway, it seems that he looked forward for a future description, or forgot to erase this name from the publication. Unfortunately, this shell could not be traced in the snail collection in Tucumán, and figures are also wanting, so it is difficult to find out whether this snail was a juvenile of the introduced *Paralaoma servilis*, or another species.

MACROSNAILS

In this section we provide an overview of the macrosnail species and its systematic position, with figures and notes of their regional range of distribution. For information about species descriptions, see the guide for land snails (in Spanish, attachment 7).

The common exotic garden snail *Helix aspersa* was found inside the Park, but only in gardens and other modified environments related to human settlements. *Otala lactea*, another exotic macrosnail common in gardens of Argentina, was not found in the Park. The endemic land snail *Plagiodontes rocae* was not found either, probably because this species has its distribution range restricted to the Curamalal mountain range.

Macrosnail diversity

1) *Plagiodontes patagonicus* (d'Orbigny, 1835)

Family **Orthalicidae**, Subfamily **Odontostominae.**


Plagiodontes patagonicus

Distribution: *Plagiodontes patagonicus* is one of the commonest snails inhabiting the Ventania system and natural environments in the Pampas plains of SW Buenos Aires Province (near Bahía Blanca city). We have found it in the 'Ernesto Tornquist' Provincial Park.

Besides its intrinsic value as a autochtonous species, studies on its ecology, conservation status and distribution of *Plagiodontes patagonicus* have the additional interest of being an important item in the diet of the endemic lizard *Pristidactylus casuhatiensis* (Cei, 1993) which is severely threatened (Lavilla *et al.*, 2000).

Note: The individuals that inhabit Sierra de la Ventana are usually larger than those inhabiting the plains. These differences, among others, were responsible for considering both forms as two separate species (Cazzaniga & Fernández-Canigia, 1985); they were recently recognized as synonyms (Cazzaniga, Pizá & Ghezzi, in press).

2) *Plagiodontes rocae* (Doering, 1881)

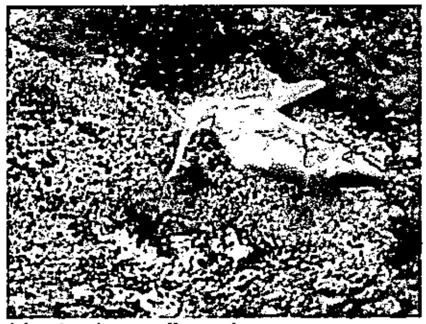
Family **Orthalicidae**, Subfamily **Odontostominae**.


Plagiodontes rocae

Distribution: Only found in the Curamalal mountain range, this is the macrosnail with the most restricted known distribution in the Ventania Mountain System. Its range lies out of protected areas; we have not found it in the 'Ernesto Tornquist' Provincial Park.

3) *Ventania avellanedae* (Doering, 1881)

Family **Orthalicidae**.


Ventania avellanedae

Distribution: Endemic to the Ventania Mountain System. It is found in the 'Ernesto Tornquist' Provincial Park.

It is remarkable that there are few studies on this endemic species, the last one being that of Parodiz (1940).

4) *Discoleus aguirrei* (Doering, 1884)

Family **Orthalicidae**, Subfamily **Bulimulinae**.

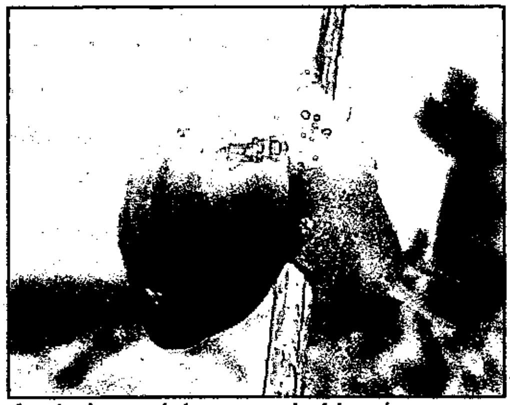

Discoleus aguirrei

Distribution: This snail inhabits the mountain systems of Buenos Aires province and La Pampa province (Lihué Calel mountains).

Note: Taxonomy of the species currently included in *Discoleus* was somewhat confusing. Specimens that were formerly considered to belong to different species (*e.g. Bulimulus ventanensis* (Pilsbry, 1896), or the long lasting name *D. azulensis* (Doering, 1881) are now subsumed under *D. aguirrei* (Doering, 1884) (Miquel, 1998).

5) *Austroborus lutescens dorbignyi* (Doering, 1876)

Family **Strophocheilidae**.


Austroborus lutescens dorbignyi

Distribution: It is found in the Ventania system and over the plains of the SW region of the Buenos Aires province. This is the southernmost species belonging to the South American Megasnails (Strophocheilidae).

6) *Succinea* spp.
Family **Succineidae**.

Distribution: *Succinea* species have a wide distribution in Argentina, always in close association to humid habitats, especially near water bodies.

7) *Helix aspersa* Müller, 1774

Family **Helicidae**.


Helix aspersa

Distribution: This is a cosmopolitan species, introduced from Europe. It is found wherever there are gardens, and it is considered a plague. It is possible to find it in human-modified environments in the Park. Fortunately, we have not found it in natural mountainous areas.

8) SLUGS

There are several species of slugs within the Park. Slugs in the families Limacidae and Milacidae are European; those in the family Vaginulidae are autochthonous.

In Buenos Aires province we can find the vaginulid *Phyllocaulis soleiformis*. In this province there are several reports of European species of the genera *Milax, Deroceras* and *Limax*. It is important to highlight that up to date there are no specific and detailed studies about the diversity and distribution of the slug fauna of the Buenos Aires province.

4. PATTERN OF DISTRIBUTION OF LAND SNAILS

This section describes both the distribution of land snail species at a general scale -relative to the management areas proposed for the Park-, and the habitats where microsnails species were found. We also contribute to a better description of the habitat of the poorly known endemic microsnail *Zilchogyra franzi*.

A more detailed description of macrosnail species distribution according to several environmental conditions is described in chapter 5.

MICROSNAILS

Methods

During field trips over all sections of the Park, we recorded the coordinates (GPS) and habitat types where the cosmopolitan *Paralaoma servilis* and the endemic *Zilchogyra franzi* were found (for taxonomical discussion see chapter 3). We specifically inspected soil, mosses, litter, caves and under stones and dung, which are habitats potentially suitable for microsnails (Hylton-Scott, 1957a).

Results and Conclusions

Table 4.1 lists the habitats where the cosmopolitan *Paralaoma servilis* and the endemic *Zilchogyra franzi* were found.

Table 4.1 Habitats of the microsnails *Zilchogyra franzi* and *Paralaoma servilis*

Species	Habitat type	(n° of locations)	Environm.	Location
Paralaoma servilis	Moss	(2)	slopes	SDLV
	Soil near roots of *Oxalis spp.*	(4)	slopes	SDLV
	Soil near roots of *Erodium* sp.	(1)	slopes	CE
	Attached to plant base (Geraniaceae)	(1)	slopes	SDLV
	In litter, *Mimosa rocae*	(2)	slopes	SDLV
	In litter, *Margyricarpus pinnatus*	(2)	slopes	SDLV
	Under stone, moist soil	(1)	slopes	SDLV
	Under herbivores dung	(2)	lowlands	Special Use Area (CE)
	Under bark of *Eucalyptus* tree	(1)	lowlands	Near houses, Intensive use area
Paralaoma servilis +*Zilchogyra franzi*	Cave, in moist soil, with ferns	(2)	gorge	SDLV
Zilchogyra franzi	Cave, in moist soil, with ferns	(1)	gorge	SDLV
Zilch. franzi (only empty shells)	Area affected by fire	(1)	slopes	SDLV

SDLV: Sierra de la Ventana mountain range, CE: Cordón Esmeralda mountain range.

It is remarkable the wide array of habitats and regions within the Park where *Paralaoma servilis* was found. It was even found under cattle dung in the Special Use Area reserved for productive activities –a clearly disturbed environment-, and under the bark of *Eucalyptus* tree, near the museum.

It was also found in several natural habitats of Cordón Esmeralda and Sierra de la Ventana mountain ranges. Many specimens were in the soil, near the roots of plants (*Oxalis* spp. and *Erodium* sp.), and others inhabited very humid places, as mosses and caves with ferns. Additionally, it was found in the litter and under the stems of the dwarf shrubs *Mimosa rocae* and *Margyricarpus pinnatus*, two species that occur in insolated and dry sites (Frangi & Bottino, 1995). The dense cover of stems might provide a good protection against desiccation.


Paralaoma servilis under the branches of the Rosaceae *Margyricarpus pinnatus*

These results are compatible with the diverse regions and habitats where this species is found around the world. *P. servilis* was already reported from various regions of Argentina under its synonymy names: in Buenos Aires, in Santa Fe province, and the rainforests of Tucumán and Misiones. It was also mentioned for SW Brazil, and recently for Bolivia. The habitats cited are, among others: under bark and fallen branches of dead trees, in moist sites, under the bark of *Eucalyptus* trees, under dry leaves, and on sandstone rocks in arid slopes (Hausdorf, 2001; Hylton Scott, 1957a,b; Weyrauch, 1965).

Paralaoma servilis was probably introduced into South America (Hausdorf, 2001). It is widespread in the Park. Time of arrival of this species probably occurred earlier than forty years ago, since in the snail collection Museo de La Plata there is a set of *Radiodiscus pilsbryi* (junior synonym of *Paralaoma servilis*) collected in 1965 in Sierra de la Ventana (Zelaya, pers. comm.). A way of introduction could have been living trees for implantation (*e.g. Eucalyptus* trees, where we found this species in the Park) or dead trunks used for construction, *e.g.* of the wire fences that set up the limits of the Park. Dispersal mechanisms were also efficient, since they are found in remote areas of the Park. Passive dispersal by means of wind or other media might be important in such a tiny and light snail. Since it is able to occupy a wide array of microhabitats in Sierra de la Ventana, the ample supply of suitable patches, may account for a rapid colonization.


View of the caves where we rediscovered the endemic snail *Zilchogyra franzi.*

The endemic *Zilchogyra franzi,* is found instead in much more restricted habitat types. We have found living snails in three occasions, only in humid gorges, where the surrounding topography prevented direct solar radiation. They were half buried into litter or moist organic soil, in caves with abundant ferns and others plant species typical of humid residences. It seems that this species might be restricted to such humid microhabitats. This statement is reinforced by two facts. First, our reported habitat agrees with that cited for the only specimen known until our work, in the original description (Weyrauch, 1965). Second, we performed extensive searches in other habitats in Sierra de la Ventana with no success in finding this endemism. However, in two occasions we found old empty shells not associated to the described habitat, in slopes of Sierra de la Ventana, in burned areas (table 4.1). This can mean that habitat requirements are not so narrow as suggested by the records of living snails, or that passive dispersal of empty shells can be important, and probably more important after fire.

Except for *Zilchogyra franzi,* other autochthonous microsnails are surprisingly not found in Sierra de la Ventana. A higher diversity would not have been surprising in this poorly studied area, since these mountains offer many potentially suitable microhabitat conditions, with abundant humid residences. Habitats as mosses, which are home for microsnails in the Patagonian Andes - where microsnails diversity is relatively high (Hylton Scott, 1957 a, b)-, are diverse and abundant in the Ventania Mountains.

MACROSNAILS

Methods

We went over different habitat types throughout all the environments inside the 'Ernesto Tornquist' Provincial Park. We used a hand-held GPS, satellite images and topographic charts for navigation at the field and for recording the position of land snail populations.

Results

In general, snails are found more frequently in Cordón Esmeralda than in the Sierra de la Ventana mountain range. In Sierra de la Ventana the distribution of snails is patchier; this is related to the heterogeneity and environment diversity in this mountain range. The highest densities are reached at some of the summits of Sierra de la Ventana, especially on 'Cerro Destierro' (1172 meters) (fig 2.2), where they crawl under stones and associate to the evergreen tiny shrub *Grindelia ventanensis* (Asteraceae) the commonest species of a typical summit plant community (Frangi & Bottino, 1995). Snail presence is rare in lowlands. At a broad scale, other general pattern of snail presences is not so clear.

The land snail *Discoleus aguirrei* appears to be the most widely distributed species at the Park, followed by *Plagiodontes patagonicus*. *Austroborus lutescens dorbignyi* and *Ventania avellanedae*, although not so common as the former two species, are also present in high numbers in some places. Adequate conditions for the four species are not clearly different. Co-ocurrences of the four species and any combination of land snails are possible.

DISTRIBUTION OF SNAILS ACCORDING TO PARK ZONATION

We discuss snail distribution according to the management areas proposed in the management plan of the Park.

Priority 1 Area: Snail distribution in this diverse area is patchy, responding to some combinations of variables. In some summits the macrosnail species *Discoleus aguirrei*, *Austroborus lutescens dorbignyi* and *Plagiodontes patagonicus* reach their highest densities. The endemic microsnail *Zilchogyra franzi* was found in gorges of mountains north and south of the route. The widespread *Paralaoma servilis* was found throughout this zone. In the smaller portion of the Park located south of the route snail populations are frequent, and sometimes abundant. Horses are absent from this area; cattle from neighbouring ranches in some opportunities entered this sector of the Park because there is no wire fence in this place.

Priority 2 and 3 Areas: The four macrosnails species *Austroborus lutescens dorbignyi*, *Discoleus aguirrei*, *Plagiodontes patagonicus* and *Ventania avellanedae* were found more or less evenly distributed and in a relatively high abundance throughout Cordón Esmeralda. This is a more or less homogeneous area, which seems to provide good habitats for macrosnails. Probable reasons are discussed in chapter 5. We also found here the widespread microsnail *Paralaoma servilis*, but not the endemic *Zilchogyra franzi*, probably because of the scarcity of low insolated gorges and humid caves.

Special Use Area: This area of less than 300 has, is reserved for agricultural activities of low environmental impact (cattle). This is a highly modified environment with deep free of rocks soils. Macrosnails were absent, but we found the microsnail *Paralaoma servilis* under dung.

Intensive Use Area: This was the only section of the Park where the widespread *Helix aspersa* was found, near houses. We also found here the introduced *Paralaoma servilis*, under the bark of an *Eucalyptus* tree. No autochthonous species was found here.

Noteworthly, these surveys revealed that important snail populations are related to areas where horses were historically absent or in low number (see section on *Horses*), and to areas with low conservation priority according to the Management Plan (see section on *Management Plan*), as Cordón Esmeralda, north of the route. It could exist a causal relationship between horse abundance and scarcity of land snail populations, which will be discussed in detail in chapter 5.

Further generalizations on snail distribution patterns are hard to settle, as habitat type and environmental parameters change in a complex manner. Microhabitat level seems to be an important scale to explain snail distribution.

5. LAND SNAIL DISTRIBUTION AND ABUNDANCE: EFFECT OF ENVIRONMENTAL VARIABLES AND HORSE IMPACT

Introduction

A major task in studies of species distribution is to identify, among the variables that are correlated with species presence and abundance, those that are biologically meaningful, *i.e.*, those having a direct effect on the species. This is especially important when some variables are putative disturbance factors whose effects one intends to assess, as is the impact of horses in the present study. This is not a minor problem, since many variables are usually strongly correlated. Hence, many spurious correlations of land snails with habitat features are likely to appear (Bishop, 1977b). Diverse studies on land snails reach to different conclusions about the importance of different sets of variables in predicting snail distribution and abundance. The outcome of the studies strongly depends on the studied species, the range of variation of the environmental variables in the study area (Ondina *et al.,* 2004), methodology employed, and the choice of variables to be measured, a decision that depends on the idea of which variables are considered as important by the researchers (Bishop, 1977b). All these factors make it difficult to straightforwardly compare the results of different studies.

Climatic and soil factors were early recognized as the most important habitat features influencing land snail distribution (*e.g.* Boycott, 1934; Bishop, 1977a). Subsequent studies stressed the importance of predation (Yom-Tov, 1970; Mordan, 1977; Abramsky *et al.*, 1990; Abramsky *et al.*, 1992) or interespecific competition (Magnin, 1993; Harvey, 1974), factors that were disregarded by Boycott (1934) of having any influence. The influence of habitat structure and vegetation physiognomy has been underlined by several works (Dillon, 1980; Cameron & Morgan-Huws, 1975; Harvey, 1974). Topographic features are important because they usually covary with climatic and other conditions that are directly important for land snails (Labaune & Magnin, 2001, 2002; Tattersfield *et al.,* 2001; Coney *et al.,* 1982). Associations with a specific composition of plants were recorded many times, but most of these relationships are believed to arise for indirect causes. The relation are belived to arise from direct response to vegetation structure, physiognomy, or to correlated soil or climatic factors, rather than to plant species composition (Bishop, 1977b; Grime & Blythe, 1969).

Introduced large herbivores, as feral horses and asses, can have a strong impact on native flora and small mammals in natural environments (Beever & Brussard, 2000; Carothers *et al.*, 1976). Particularly, grazing is known to have a profound impact on land snail community composition. The reduced vegetation height augments local insolation and temperature, and homogeneizes vegetation structure, thus reducing the number of niches for land snails. As a consequence, grazed areas show a reduced snail diversity, low species richness (Labaune & Magnin, 2002), and a greater proportion of xerophil snail species (Labaune & Magnin, 2002; Cameron & Morgan-Huws, 1975; Boycott, 1934). The 'Ernesto Tornquist' Provincial Park (ETPP) has more than forty years of feral horses grazing. The effect of grazing on bird communities was recently assessed in the Park (Zalba & Cozzani, 2004), but its impact on invertebrates in general, and on land snails in particular, is totally unknown up to date.

The ETPP presents adequate conditions for studying the relationship of environmental factors with land snails. It is a reserve which is located in the Ventania Mountains, and area having the greatest diversity of snails in the Pampas, with endemic species and others occurring also in the plain surroundings, and strong variation in climatic and other ecological factors (Kristensen & Frangi, 1995) potentially important for land snails. The knowledge of factors affecting distribution and abundance of land snails is important both for land snail conservation and for conservation of its natural predators, *e.g.* the endangered endemic lizard *Pristidactylus casuhatiensis*, a specialist predator of land snails.

In the present study we analyse the effect of topography, soil features, floristic composition, climatic conditions, horse impact and habitat structure on land snail distribution and abundance, at two geographical scales. There were no such ecological studies on land snails in Argentina so far.

Materials and methods

Study area

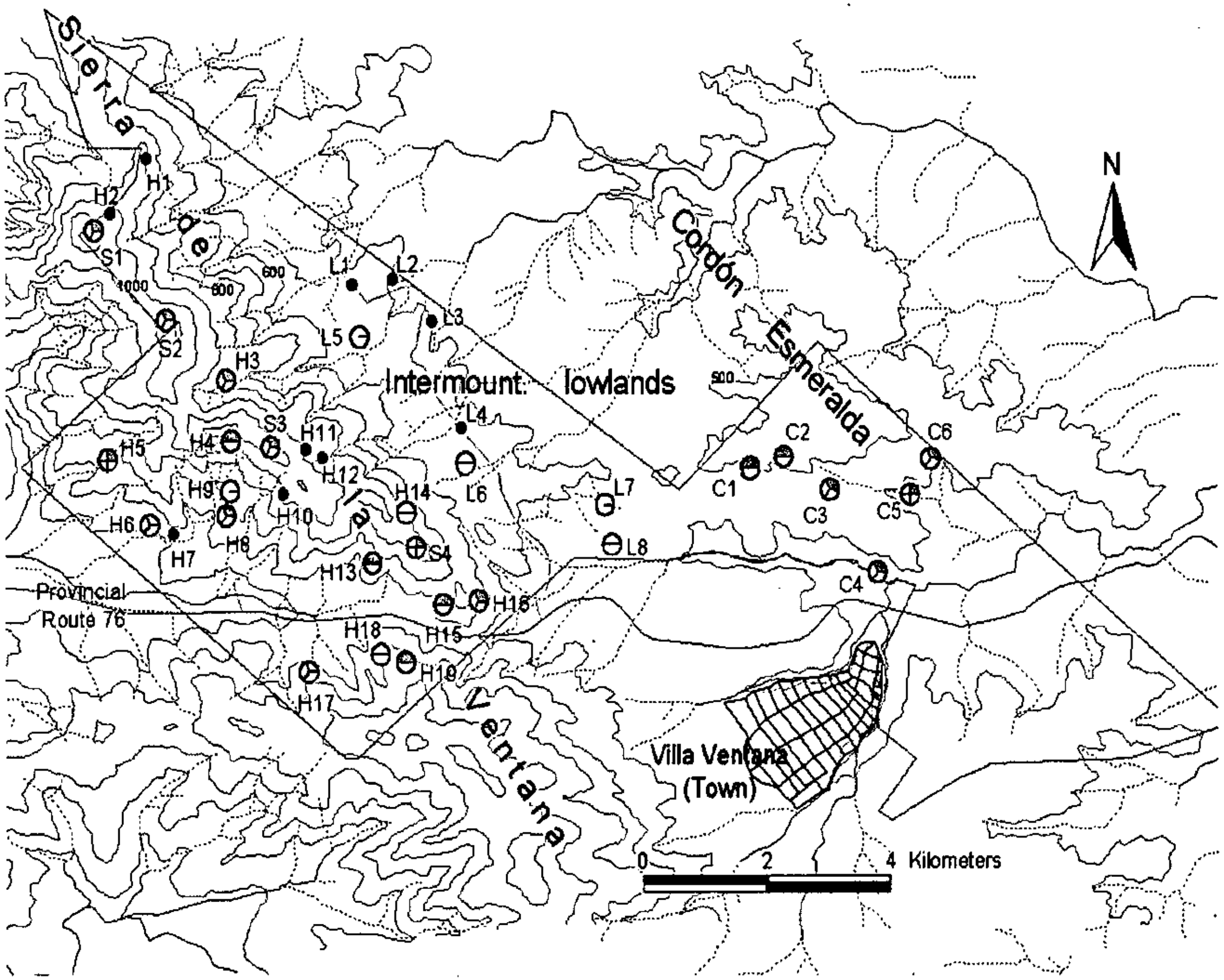
Samples were taken throughout the natural environments of the Park, including summits, lowlands and slopes of Sierra de la Ventana and Cordón Esmeralda mountain ranges. We provided a detailed habitat description in chapter 1.

Land snail sampling

Sampling was carried out during late spring and early summer 2002, in periods when snails were inactive, *i.e.*, days with no rainfall.

A two-stage sampling procedure was adopted. First, 37 sampling areas were randomly selected in various strata inside the Park: summits, lowlands, NE and SW-facing hillsides of Sierra de la Ventana, and Cordón Esmeralda mountain range (fig. 5.1 localizes the sampling areas in the study area). We used a hand-held GPS for navigation to sampling areas. Second, in each sampling area –a circle of about 40 meters diameter- two to five plots of 1 x 10 m^2 were selected, with 125 plots in total. We selected, when present, at least one plot in rocky outcrops habitat, and one in non-rocky grasslands habitat per sampling area. At each plot, we counted both living snails and empty shells.

Figure 5.1 Map of Sampling Areas



References

Mountainous zone of sampling areas

Summits of Sierra de la Ventana
S1 – S4

Hillsides of Sierra de la Ventana
H1 – H19

Intermountainous lowlands
L1 – L8

Cordón Esmeralda
C1 – C6

Colour coding for snail species presence

Yellow
Ventania avellanedae

Green
Austroborus lutescens dorbignyi

Blue
Plagiodontes patagonicus

Red
Discoleus aguirrei

Resting sites of living snails were recorded and classified into five main categories: attached to rocks, under stones, in fissures or crevices, associated to plants, and associated to the shrub *Grindelia ventanensis*.

Environmental variables

Environmental variables recorded include topography, soil physicochemical variables, floristic composition, habitat structure, horse impact index, climatic and other environmental indexes derived from floristic composition. Some variables are related to the sampling area as a whole, while others refer only to individual plots.

Fourteen variables of surface cover were used to describe the habitat structure of plots. Three variables described the cover of different vegetation physiognomy: shrubs, grasses and ferns; four variables described the cover of different vegetation layers: 0-10 cm, 11-25 cm, 26-50 cm, >50 cm; four variables described the cover of different rock heights: 0-10 cm, 11-25 cm, 26-50 cm, >50 cm; and three additional variables described the total cover of rocks, total cover of vegetation and the cover ratio of vegetation to rocks. Coding used for cover description was: 0: 0%, 1: 1-5%, 2: 6-10%, 3: 11-25%, 4: 26-50%, 5: 51-75%, 6: 76-100%.

A horse impact index was assigned to each plot based on the indirect evidence of presence of dung, grazing and trampling. The index took integer values from 0 –no evidence-, to 2 –maximum impact.

At each plot, we collected samples about 5 cm deep of superficial soil, which were sieved through a 2 mm mesh at the laboratory for the analysis of 12 physicochemical variables, carried out by LANAQUI (Universidad Nacional del Sur). The soil variables measured were: organic carbon and total nitrogen contents, carbon to nitrogen ratio, pH, concentration of sodium, potassium, magnesium and calcium, clay fraction, silt fraction, sand fraction and textural class.

Plants were identified at the laboratory by using Cabrera (1963-1970) and Torres (1993); the nomenclature follows Long and Grassini (1997). Plant species were grouped into the floristic groups described in Frangi & Bottino (1995). A floristic group is a set of plant species that tend to occur together in response to certain combinations of environmental conditions. The floristic groups were used as variables, whose values were the number of species recorded for each floristic group. Table 5.1 provides the species composition and table 5.2 the environmental conditions associated with each floristic group.

Indexes of disturbance (*e.g.* overgrazing), fissures in rocks, local humidity and insolation were calculated for each plot with the information of local environmental conditions provided by the floristic groups, as follows:

$$I_e = \frac{\sum c_{ei} \cdot f_i}{\sum f_i},$$

where I_e: index of the environmental condition *e*, c_{ei}: floristic group coefficient *i* of environmental condition *e*, and f_i: number of species of floristic group *i*. Table 5.2 shows the coefficients for each index and floristic group.

We also recorded several variables for sampling areas. Topographic variables recorded were slope angle and altitude. A horse impact index ranging from 0 to 3 was also computed, as well as the humidity, insolation and disturbance indexes, in the same manner as described for plots. Additionally, we calculated mean values of the soil variables that showed little variation among plots within sampling areas: organic carbon, total nitrogen, carbon to nitrogen ratio, pH, and contents of sodium, magnesium, potassium and calcium.

Data analysis

The association degree among land snail species was analyzed by the Cole's index. Values can range from 1 to –1; the sign of the index indicates whether the relationship is positive or negative.

We used Spearman's rank-order correlation coefficients and principal component analysis for the study of relationships among variables.

The response of each species to single variables was analyzed by means of corrected frequencies profiles (Daget & Godron, 1982). This technique requires the environmental variables being divided into classes; table 5.3 reports the values of the class intervals used and the number of samples recorded in each class. Corrected frequencies (*CF*) were calculated as follows:

$$CF = \frac{U(K)/R(K)}{U(E)/N},$$

where $U(K)$: number of presences of the species in the variable class *K*, $R(K)$: number of samples in the variable class *K*, $U(E)$: total number of samples with land snail presence, *N*: total number of samples. Values of $CF > 1$ indicate preference, <1, rejection; the statistical significance of these responses were calculated according to Gauthier *et al.* (1977). The overall significance of species' response to single environmental variables was evaluated by chi^2-tests.

The analyses were performed both at the geographical scale of sampling areas (SAA: sampling area analysis) and at the scale of individual plots (CPA: complete plot analysis, and RPA: restricted plot analysis). Some variables, like topographic features, could be affecting snail populations at a geographical scale of sampling areas rather than to plots. Other variables, like those describing habitat structure, are characteristic of plots. Some variables were computed for both geographical scales, for example, soil chemical variables.

We calculated mean values of chemical soil variables for sampling areas, but, as there was some variation among plots inside sampling areas, we also computed chemical soil variables for individual plots. Since some variables can be important at the microgeographical scale, and absences at sampling area level could respond to states of other variables or to historical events, we also performed additional analyses at the plot level, excluding plots of sampling areas where the snail species were not recorded (RPA). Excluding these potentially confounding cases, we had a better assessment of the performance of variables that act at a microgeographical level. The variables used in these approaches are reported in tables 5.3 (SAA) and 5.4 (RPA, CPA).

Snails were considered present when living or dead snails were recorded either for the plot or for the sampling area. As living snails are sometimes harder to find than dead snails, the latter can be used as evidence for habitat use, though it can also happen that empty shells are transported to places not inhabited by living snails. In an attempt to circumvent this problem, we performed two additional analyses. One analysis excluding the plots that contained exclusively one dead specimen, and the other excluding dead snails at all, *i.e.* considering as inhabited only those with living snails. We report these results only when they differ qualitatively from the first approach.

Table 5.1 Plant species recorded for each floristic group according to Frangi & Bottino (1995). *Group*: floristic group, *Nº spp.*: number of species recorded for each floristic group.

G	Nº spp	Species
G1	3	*Festuca ventanicola, Grindelia ventanensis, Nierembergia tandilensis.*
G2	1	*Festuca pampeana.*
G3	3	*Luzula hieronymi, Woodsia montevidensis, Gnaphalium cheirantifolium.*
G4	9	*Stipa juncoides, Stipa pampeana, Grindelia buphtalmoides, Senecio ventanensis, Stevia satureiaefolia* var. *ventanensis, Cardionema ramosissimum, Cerastium mollissimum, Notholaena squamosa, Pellaea ternifolia.*
G5	3	*Adiantum spp., Lathyrus tomentosus, Polypodium argentinum.*
G6	3	*Poa iridifolia, Elaphoglossum gayanum, Ctenopteris peruviana.*
G7	4	*Uncinia phleoides, Polystichum plicatum, Acaena ovalifolia, Blechnum chilense.*
G8	3	*Cheilanthes buchtiennii, Cheilanthes micropteris, Tillandsia* sp.
G9	1	*Plantago bismarckii.*
G10	15	*Aristida spegazzini, Schizachyrium spicatum, Eryngium nudicaule, Pavonia cymbalaria, Facelis retusa, Hysterionica pinifolia, Mimosa rocae, Euphorbia portulacoides, Achyroline satureioides, Adesmia pampeana, Zexmenia buphtalmiflora, Eupatorium tanacetifolium, Gomphrena perennis, Blumembachia insignis, Sommerfeltia spinulosa.*
G11	4	*Piptochaetium lejopodum, Margyricarpus pinnatus, Arjona tuberosa, Dichondra sericea* var. *holosericea*
G12	6	*Cynosurus echinatus, Elionurus muticus, Eragrostis lugens, Sorghastrum pellitum, Stipa filiculmis, Convolvulus hermanniae.*
G13	4	*Piptochaetium hackelii + P. napostaense, Stipa melanosperma, Baccharis rufescens* var. *ventanicola, Dichondra sericea* var. *sericea.*
G14	5	*Aristida murina, Piptochaetium stipoides* var *verruculosum, Holocheilus brasiliensis, Daucus pusillus, Linum selaginoides.*
G15	1	*Baccharis articulata.*
G17	3	*Stipa trichotoma, Discaria americana, Pfaffia gnaphalioides.*
G18	2	*Plantago patagonica, Rhynchosia diversifolia* var. *prostata.*
G19	13	*Aira caryophyllea, Calotheca brizoides, Danthonia cirrata, Piptochaetium montevidense, Lucilia acutifolia, Geranium albicans, Cuphea glutinosa, Plantago myosurus, Oenothera odorata, Oxalis articulata, Gamochaeta americana, Cerastium arvense, Hypochoeris variegata.*
G20	2	*Paspalum quadrifarium, Piptochaetium lasianthum.*
G22	3	*Lolium multiflorum, Piptochaetium medium, Stipa neesiana.*
G25	2	*Centaurea solstitialis, Medicago minima.*
G29	1	*Cereus aethiops.*

Table 5.2. Ecological conditions indicated by the floristic groups, extracted from Frangi & Bottino (1995) and coefficients used for the calculation of environmental indexes. c_M: moisture coefficient, c_I: insolation coefficient, c_D: disturbance coefficient, c_F: fissures coefficient.

G_i	Ecological Conditions	c_M	c_I	c_D	c_F
G1	Shadow and cold. Gravel or rocky substratum. Eroded, moist soils.	1	1	0	0
G2	Cold. Steep slopes of S aspect, >500m. Deep, moist soil. Boulders.	1	0	0	0
G3	Rocky moist soils. Moderate insolation.	1	0	0	0
G4	Fissures, crevices. (Chasmophytes)	0	0	0	1
G5	Shadow. Moist and fresh sites. (Chasmophytes).	1	-2	0	0
G6	Semi-shadow. On 'suspended' soils. (Chasmophytes)	0	-1	0	0
G7	Shadow. High elevations, S aspect slopes. Cold, organic and moist substratum. (Chasmophytes)	2	-2	0	0
G8	Dry sites, high temperatures, high insolation. N aspect slopes, low elevations. Fissures, crevices. Incipient, dry soil. (Chasmophytes)	-1	1	0	1
G9	Medium S hillsides. (Chasmoxerophytes)	0	0	0	0
G10	Rocky soils. Insolated rocky outcrops, fissures and crevices. Superficial soils.	0	1	0	1
G11	Superficial soils. Crevices and fissures. Dry sites.	-1	0	0	1
G12	Insolated sites. Well-drained, generally rocky soils. Hillsides.	0	1	0	0
G13	Insolated sites. Poor in rocks and gravel.	0	1	0	0
G14	Dry, superficial soils. Overgrazing.	0	0	1	0
G15	Gravel. Disturbance.	0	0	1	0
G17	Gravel. Overgrazing.	-1	0	0	0
G18	Dry superficial soils.	-1	0	0	0
G19	Widespread, companion species.	0	0	0	0
G20	Very moist, deep soils. Periodically flooded. Valley floor.	3 or 0*	0	0	0
G22	Moderate to deep, mesic soils.	0	0	0	0
G25	Disturbance. Overgrazing. Abandoned cultivated soils.	0	0	1	0
G29	Deep and dry soils. Sometimes among rocks. <500m. Warm sites.	0	0	0	0

* 0 when the index is calculated for sampling area (mesoclimate), and 3 when calculated for plots (microhabitat)

Table 5.3a. Variables for plot level analyses.

Variables	Class Intervals 1	2	3	4	5	Number of samples 1	2	3	4	5	N°
rocks	0	1 to 2	3 to 4	5 to 6		22	25	20	58		125
vegetation	0 to 3	4	5	6		8	28	23	66		125
veg./rocks	-2	-1	0	1	2	8	29	32	33	23	125
rocks-1	0	1 to 2	3 to 4	5 to 6		75	27	16	7		125
rocks-2	0	1 to 3	4	5 to 6		95	14	11	5		125
rocks-3	0	1 to 3	4	5 to 6		98	9	10	8		125
rocks-4	0	1 to 2	3 to 4	5 to 6		91	8	9	17		125
veg-1	0	1 to 4	5 to 6			81	33	11			125
veg-2	0	1 to 2	3 to 4	5 to 6		30	23	50	22		125
veg-3	0	1 to 2	3 to 4	5 to 6		43	21	48	13		125
veg-4	0	1 to 2	3 to 4	5 to 6		95	3	11	16		125
grasses	0 to 2	3 to 4	5	6		11	52	16	46		125
shrubs	0	1 to 2	3 to 4	5 to 6		35	53	32	5		125
ferns	0	1 to 2	3 to 6			108	12	5			125
horse index	0	1	2			76	25	24			125
Organic carbon	2.33 to 5.57	5.58 to 9	9.01 to 16.15			35	46	41			122
total nitrogen	0.12 to 0.29	0.29 to 0.5	0.51 to 0.7	0.71 to 1.13		18	40	40	24		122
C/N	8 to 14	14 to 19	20 to 36			17	95	10			122
PH	4 to 4.9	4.9 to 5.5	5.6 to 6.4			26	51	45			122
Na	0.03 to 0.19	0.19 to 0.3	0.31 to 0.52			32	63	27			122
Mg	0.22 to 2.08	2.09 to 3.5	3.6 to 5.3			40	54	28			122
K	0.17 to 0.54	0.54 to 0.84	0.85 to 2.01			43	50	29			122
Ca	0.62 to 5	5.1 to 8	8.1 to 14	15 to 25		21	32	55	14		122
Clay	5 to 12	12 to 16	17 to 22			35	43	44			122
Silt	1 to 11	11 to 16	17 to 25			37	54	31			122
Sand	60 to 70	70 to 76	77 to 87			32	45	45			122
textural class	1	2	3	5		19	13	77	13		122

Table 5.3b. Variables for plot level analysis (cont.)

Variables	Class Intervals				N° of samples				
	1	*2*	*3*	*4*	*1*	*2*	*3*	*4*	N°Tot
G. ventanensis	0	1			112	13			125
G01	0	1 to 2			110	15			125
G02	0	1			116	9			125
G03	0	1 to 2			100	25			125
G04	0	1	2	3 to 4	58	38	21	8	125
G05	0	1			112	13			125
G06	0	1			116	9			125
G07	0	1 to 4			118	7			125
G08	0	1			119	6			125
G10	0	2	3	4 to 8	32	38	21	34	125
G11	0	1	2 to 3		73	33	19		125
G12	0	1	2 to 3		54	44	27		125
G13	0	1	2 to 4		48	47	30		125
G14	0	1	2 to 3		81	28	16		125
G15	0	1			111	14			125
G17	0	1	2 to 3		75	34	16		125
G18	0	1			111	14			125
G20	0	1			115	10			125
G22	0	1 to 3			103	22			125
local humidity	-0.33 to -0.19	-0.18 to 0	0.01 to 0.24	0.25 to 3	25	30	21	16	92
insolation	-1.13 to 0	0 to 0.44	0.45 to 0.75		8	58	51		117
disturbance	0	0.01 to 0.1	0.11 to 0.25		74	23	28		125
fissures	0	0.01 to 0.25	0.26 to 0.5	0.51 to 1	15	27	57	26	125

Table 5.4. Variables for sampling area level analysis

Variables	Class Intervals 1	2	3	4	N° samples 1	2	3	4	N° tot
mount. zone*	C.Esmer.	Lowlands	Hillsides	Summits	4	19	8	6	37
altitude	400 to 500	501 to 650	651 to 950	951 to 1150	12	10	11	4	37
slope	0 to 12	13 to 32	33 to 47	48 to 65	10	18	8	1	37
horse index	0	1	2	3	13	2	11	11	37
humidity	-0.30 to -0.16	-0.15 to 0	0.01 to 0.24	0.25 to 1.14	9	16	9	3	37
insolation	-1 to 0	0.01 to 0.4	0.41 to 0.65		3	14	20		37
disturbance	0	0.01 to 0.09	0.1 to 0.22		12	19	6		37
organic carbon	2.7 to 5	5.1 to 8.3	8.4 to 12.5		9	13	15		37
total nitrogen	0.20 to 0.36	0.37 to 0.6	0.61 to 0.95		10	13	14		37
C/N	9.5 to 12	13 to 18	18.1 to 23.9		2	31	4		37
pH	4.4 to 4.9	4.9 to 5.5	5.6 to 6.1		6	16	15		37
Na	0.06 to 0.18	0.19 to 0.29	0.30 to 0.44		9	17	11		37
Mg	1.1 to 2	2.1 to 3	3.1 to 4.5		8	15	14		37
K	0.33 to 0.6	0.61 to 0.87	0.88 to 1.84		16	17	4		37
Ca	4 to 6.7	6.8 to 10.6	10.7 to 18.7		9	19	9		37

Results

Relationships among land snails

Sampling areas and plots with dead snails were more frequent than those with living snails for all species. All sampling areas and most plots where living snails were found, also contained dead snails (table 5.5). Hereafter we will present the results including both living and dead snails together, otherwise stated. We recorded snails in 73% (27/37) of the sampling areas and 54% (67/125) of the plots.

The most frequent and abundant species was *Discoleus aguirrei*, followed by *Plagiodontes patagonicus* (table 5.5). *Discoleus aguirrei* is found in all sampling areas inhabited by snails, and in 90% of the inhabited plots, the remaining 10% corresponds to plots with *P. patagonicus*, either alone or in the company of *A. l. dorbignyi*. *Ventania avellanedae* and *Austroborus lutescens dorbignyi* always co-occured with either *D. aguirrei* or *P. patagonicus*.

Therefore, *V. avellanedae* occured always in plots inhabited by *D. aguirrei* (Cole's association index= 1, table 5). *Austroborus lutescens dorbignyi* showed a high association with *D. aguirrei* and especially with *P. patagonicus*. The weakest relationships were between *V. avellanedae* and both *P. patagonicus* and *A. l. dorbignyi* (both association indexes = 0.29 at the plot level). The four species were found together in 10% of the plots.

Table 5.5 Presence and abundance of land snails in plots and sampling areas, and association indexes among land snails.

	Sampling areas N total =37 **Nº of areas inhabited:**			**Plots** N total=125 **Nº of plots inhabited:**			**Abundance**		**Cole's association index** (l+d, plots)			
	living	dead	l+d	living	dead	l+d	living	dead	*D.a.*	*P.p.*	*A.l.d.*	*V.a.*
D.a.	23	27	27	39	56	60	349	625	-	0,68	0,74	1,00
P.p.	10	19	19	17	41	42	191	372	0,68	-	0,86	0,29
A.l.d.	1	13	13	2	21	22	3	60	0,74	0,86	-	0,29
V.a.	6	9	9	8	16	17	46	169	1,00	0,29	0,29	-
All species	23	27	27	42	65	67						

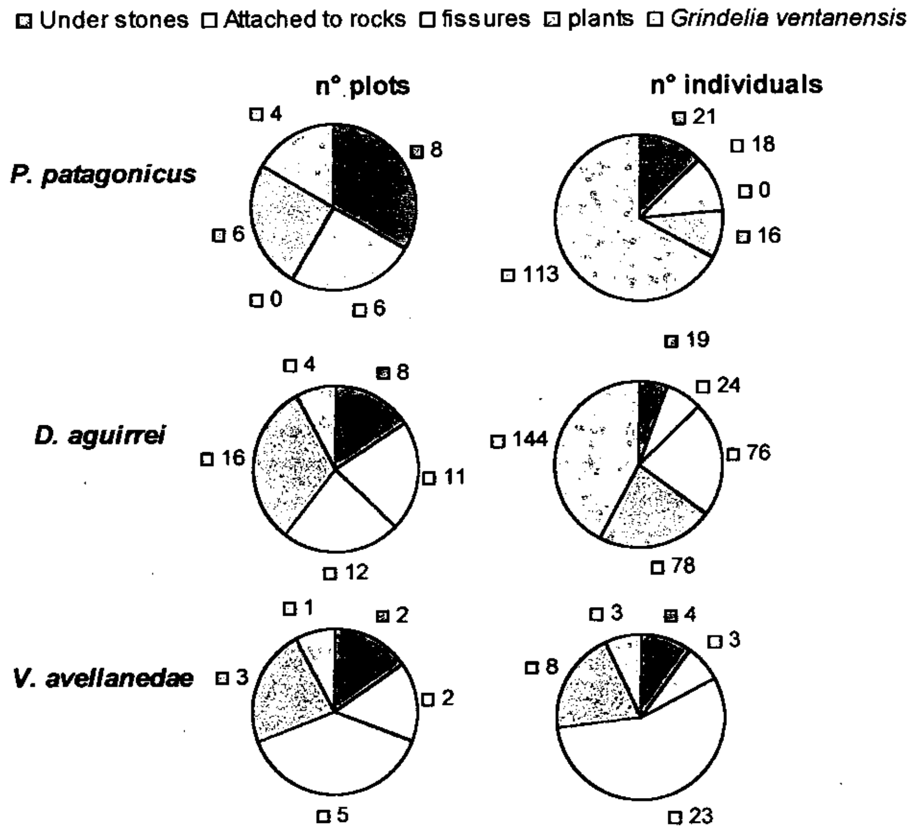
l+d: living and dead snails considered together. *D.a.: Discoleus aguirrei, P.p: Plagiodontes patagonicus, A.l.d: Austroborus lutescens dorbignyi, V.a.:Ventania avellanedae*

Resting sites

The number of living snails recorded in each resting category and the number of plots where the different microhabitats are recorded are reported in figure 5.2. As more than one category could be reported per plot, the sum of categories sometimes exceed the total number of inhabited plots (table 5.5).

Both *D. aguirrei* and *V. avellanedae* were recorded in all kind of microhabitats. We did not record *P. patagonicus* in fissures, and the only three living *A. l. dorbignyi* recorded were found under the shrub *Grindelia ventanensis*. This shrub is also especially important for *P. patagonicus* and *D. aguirrei*. Not only the highest number of specimens for both species were related to the presence of this plant in summits, but also corresponded to the highest densities recorded (*P. patagonicus, D. aguirrei*). Some *P. patagonicus* reported under stones were found half burried into the soil, while *D. aguirrei* and *V. avellanedae* were usually attached to rocks.

Figure 5.2. Associations of snails with microhabitats. Data on *Austroborus lutescens dorbignyi* are not displayed (all specimens were associated to *Grindelia ventanensis*).

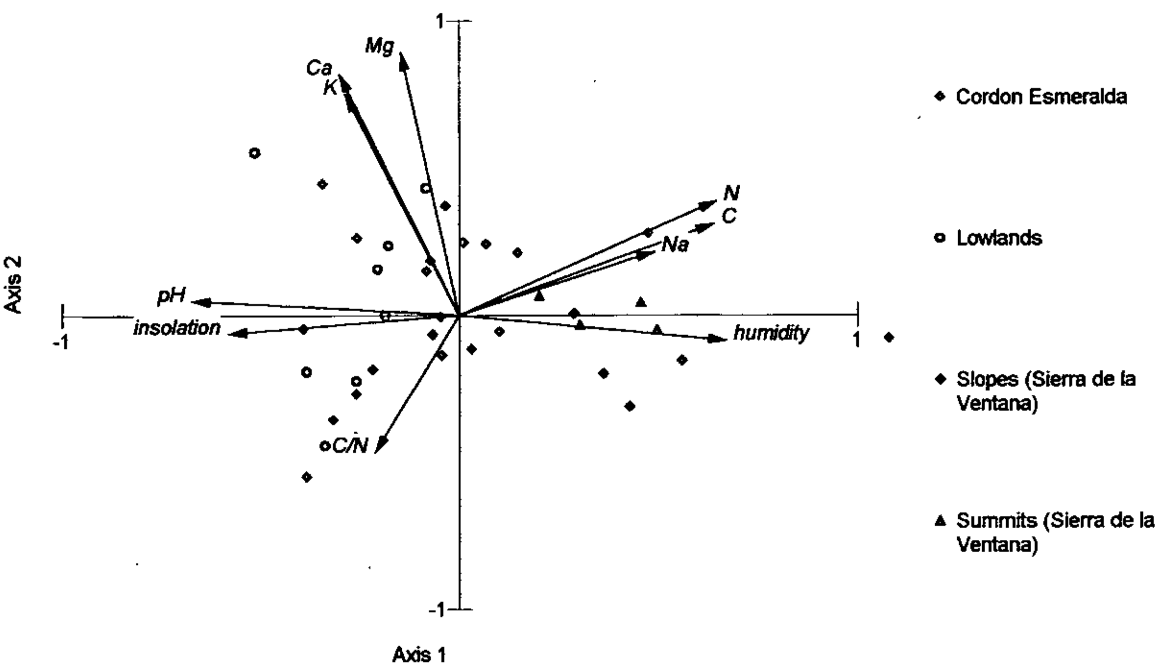


Environmental variables: regional distribution and relationships

Chemical properties of the soil showed most of its variation among sampling areas, with little variation among plots within each sampling area. This pattern was notably stronger for C, N, C/N, pH and Na, while the remaining base cations had more variation among plots within sampling areas. Therefore, chemical properties of the soil and their relationships with mesoclimatic conditions were studied at the level of sampling areas.

Soil and mesoclimatic variables showed strong correlations, and a clear regional pattern of variation. High levels of pH and low content of C, total N and Na were related to conditions of high insolation and low humidity, as can be seen in the Euclidean biplot of PCA (figure 5.3). The first two axes accounted for 67.4% of the variance. Axis 1 separates sampling areas of Cordón Esmeralda and lowlands (with conditions of high insolation and pH, low humidity, and low contents of N, C and Na) from summits (with the opposite conditions). Slopes had a quite wide variation of conditions, from very humid, as found in low insolated gorges and some SW slopes, to the highly insolated hillsides of northern aspect. The base cations Ca, K, and Mg have positive loadings with the second axis. The areas with high values on the second axis correspond to some lowlands and slopes, but the geographical pattern is not so clear.

Figure 5.3. PCA of sampling areas grouped into mountainos zones. Variables: chemical soil variables and mesoclimatic conditions



Vector scaling: 1.60

Table 5.6. PCA of sampling areas.
Mesoclimatic and chemical soil variables.

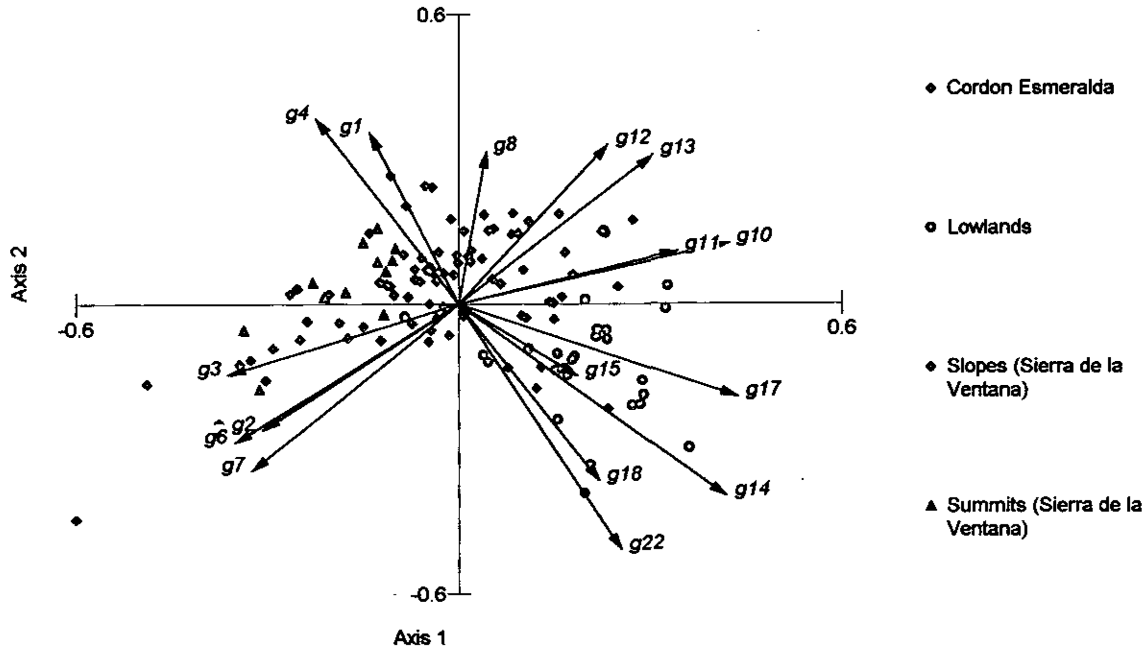
Variable	Principal component I	II
insolation	-0.37	-0.04
humidity	0.42	-0.05
carbon	0.40	0.19
nitogen	0.40	0.24
C/N	-0.13	-0.29
pH	-0.42	0.03
Na	0.31	0.13
Mg	-0.09	0.56
K	-0.18	0.47
Ca	-0.19	0.51
Eigenvalue	4.259	2.478
Cum. Percentage explained	42.59	67.36

Figure 5.4 shows the first two axes of the Euclidean biplot of the PCA on the standardized floristic group variables. The first axis accounts for only 19% of the total variance (table 5.7), but it still captures enough meaningful information for describing the grouping of related variables and the general pattern of distribution of floristic groups. The floristic groups related to climatic conditions of humidity and low insolation (table 5.2) have negative loadings with the first component (table 5.7), while most of the variables related to the opposite climatic conditions bear positive loadings. The first component discriminates plots of different geographic origin. Plots of the summits have negative values on the first axis, while plots from lowlands and Cordón Esmeralda have positive values. Plots belonging to highly variable slopes of Sierra de la Ventana have a great dispersion, and are not separated. Part of the variation of the remaining components probably accounts for the microhabitat floristic variability between rocky outcrops and soils.

Table 5.7. PCA of plots. Floristic groups variables

Variables	Principal component I	II	III	IV	V	VI
g1	-0.12	0.29	0.20	-0.44	-0.08	0.22
g2	-0.25	-0.21	0.14	0.38	0.08	-0.11
g3	-0.29	-0.12	0.27	-0.18	0.25	-0.13
g4	-0.18	0.31	0.42	0.08	-0.14	-0.11
g5	-0.06	-0.08	0.11	0.13	-0.42	0.14
g6	-0.29	-0.23	0.22	0.22	0.10	-0.14
g7	-0.26	-0.28	0.16	0.03	0.22	-0.20
g8	0.04	0.26	0.23	-0.20	0.47	0.31
g10	0.35	0.10	0.42	-0.10	0.01	-0.28
g11	0.28	0.09	0.34	0.11	-0.32	-0.22
g12	0.19	0.27	-0.17	0.42	0.26	-0.01
g13	0.25	0.25	-0.09	0.36	0.21	-0.03
g14	0.34	-0.32	0.22	-0.07	0.04	0.21
g15	0.15	-0.12	-0.08	-0.23	0.40	-0.25
g17	0.36	-0.16	0.25	0.07	0.03	-0.16
g18	0.18	-0.30	0.17	0.14	0.20	0.36
g20	0.09	-0.01	-0.25	-0.28	0.00	-0.58
g22	0.21	-0.41	-0.14	-0.18	-0.17	0.12
Eigenvalues	3.44	1.79	1.51	1.38	1.23	1.18
Cum. Percentage	19.11	29.03	37.43	45.10	51.93	58.49

Figure 5.4. PCA of plots grouped by mountainous zone. Floristic groups variables.



Vector scaling: 1.13

Other variables with strong geographical component are horse impact and silt fraction. Horse impact is zero in Cordón Esmeralda and in the slopes of Sierra de la Ventana that are located south of route #76, and highest in most sampling areas of lowlands. Horse impact is intermediate in summits, and variable in slopes of Sierra de la Ventana. Silt fraction tends to be low at Cordón Esmeralda and lowlands.

Habitat structure variables, vegetation and rocks, have a strong negative correlation since they describe substrate cover.

Responses of land snails to environmental variables

The most significant variables according to chi^2-tests and the generalized type of response given by the corrected frequencies profile are shown in table 5.8 at sampling area level and in table 5.9 at plot level. Figure 5.5 and 5.6 show the responses to the qualitative variables mountainous zone and textural class respectively. Although the variables reported as important for each species varied, the qualitative response was similar, allowing a joint approach of these results.

The most significant generalized responses at sampling area level are the rejection of horses and differential frequency of occurrences in diverse mountainous zones (table 5.8). No significant variables were found for *V. avellanedae* at sampling area level.

The mountainous zones Cordón Esmeralda and summits had a higher proportion of snail presence than slopes, and especially, than lowlands.

Ventania avellanedae and *D. aguirrei* were recorded in lowlands, but always in transition areas either to the slopes of Sierra de la Ventana or to Cordón Esmeralda. Instead, *Plagiodontes patagonicus* and *A. l. dorbignyi,* were absent from lowlands.

The most significant generalized responses at plot level were found for the habitat structure variables and, among plants, for the preference for *Grindelia ventanensis* and floristic group 1, to which it belongs. The remaining variables varied in significance according to the considered species.

Although the analysis that excluded plots of uninhabited sampling areas (RPA column in table 5.9) contained less data, many responses of habitat structure variables were still statistically significant. Moreover, sometimes the significance of a response increased, suggesting that these variables exert their influence at a microgeographical level. This happened to a lesser extent in the floristic composition variables. This could indicate some floristic composition differences between, for example, rocky and non-rocky habitats within sampling areas.

There were no negative responses to habitat structure variables. In general, there is a preference for rocky sites, sites with no rocks being rejected. Related to this response, there is a preference for intermediate values of vegetation cover. A lower preference for high values of vegetation might be associated with the fact that increasing values of vegetation cover are related to decreasing cover of rocks (r_s = -0.85, n=125), which are preferred.

A clearer picture of this can be seen in the response of the vegetation/rocks cover ratio. There is a tendency to reject plots in which either vegetation or rocks clearly dominate the substrate, more or less equal covers of vegetation and rocks being preferred. The assessment of the significance of the response to rock-dominated substratum is poor because there are few data for this class. Inhabited plots with vegetation dominance are mostly plots of summits, associated with the shrub *Grindelia ventanenis.* Responses are qualitatively similar for all species, significances for *A. l. dorbignyi* and *V. avellanedae* being usually weaker, because fewer data are available.

The responses of rock and vegetation variables divided into height strata usually yielded the same results as the variables rocks and vegetation, but with less significant responses, because there are fewer data. Rocks of intermediate height, which are the most frequent, are preferred, and vegetation of intermediate height, also the most frequent category, have usually an unimodal response. Responses and significances differed, however, according to the snail species considered (table 5.9).

There was a generalised unimodal response to grass cover, similar to vegetation. Grass physiognomy type was the most frequent one and consequently, the most related to vegetation (r_s= 0.75, n=125). Shrubs, which have lesser cover values than grasses, were preferred. The response to ferns was not significant for all snail species.

Austroborus lutescens dorbignyi, *P. patagonicus* and *D. aguirrei* presented meaningful responses to some soil textural variables. There was a tendency for preference for sandy condition and avoidance of clay. Clay rejection at plot level was important in *A. l. dorbignyi*, and to a lesser extent in *P. patagonicus*. *Plagiodontes patagonicus* also showed a preference for the sandy textural class sandy-loam, and there was some evidence for sand fraction preference by *A. l. dorbignyi* at the sampling area level and by *D. aguirrei* at plot level. *Discoleus aguirrei*, *P. patagonicus* and *A. l. dorbignyi* all had a concave response to silt fraction.

In addition to the generalised responses reported earlier, we can add some species-specific responses. Fissure seems to be important for *Discoleus aguirrei*; this can be seen in the positive response to the fissure index and to the floristic groups 4, 10 and 11, which are indicative of these conditions. There is a significant negative response to floristic group 22. The response to insolation was significant at the level of sampling areas and plots; the response curve was concave, intermediate values of insolation being significantly rejected. As regards to chemical soil variables, there is a positive response to C/N ratio, a concave response to N and Na and an unimodal response to C and Mg.

The response of *P. patagonicus* to insolation was concave, similar to *D. aguirrei*. *Plagiodontes patagonicus* had a significant positive response to fissures in the reduced data set of inhabited sampling areas. There was also rejection for horses at the plot level, and sampling area level.

Plagiodontes patagonicus and *A. l. dorbignyi* rejected the floristic groups 14 and 15, related to disturbance conditions and overgrazing, and both species had a negative response to the disturbance index.

Austroborus lutescens dorbignyi was the only species with a clear response to mesoclimatic conditions. It preferred sampling areas with higher humidity, though the response is not significant at the 5% probability level. This species also preferred the floristic groups 3 and 6, which contain some ferns and indicate humid conditions. We detected preference for Na and a concave response to N and C.

Ventania avellanedae did not show many significant responses to horses, soil variables, floristic variables and related indices. The scarce data for this species probably made it difficult to detect some responses.

The analyses referred above were done considering jointly dead and alive snails. We did not conduct analyses considering only living *Austroborus lutescens dorbignyi*, because we found only two plots with living specimens. The analyses conducted considering only living *D. aguirrei* and *V. avellanedae* did not differ qualitatively from the results reported above; only the significances of the importance of some variables were usually slightly lower because of the reduced set of presences.

Some noteworthy differences in response were found for *Plagiodontes patagonicus*, not only by considering solely living snails, but also by just computing as absent those plots that had only a single dead *P. patagonicus*. Three out of the eight plots excluded were non-rocky grassland habitats that accompanied inhabited rocky plots. Consequently, there was an increased evidence for the preference for rocks. The other five excluded plots belonged to the three less insolated and most humid sampling areas, and accounted for a qualitative difference in response: a tendency to prefer less humid and more insolated plots. The Cole's association index with *A. l. dorbignyi*, which tends to prefer these conditions, suffered a slight decrease from 0.86 to 0.69. The remaining responses did not vary considerably.

Table 5.8. Generalized responses of land snail species to environmental variables at sampling area level, according to corrected frequencies

Positive responses					**Concave and unimodal responses**					**Negative responses**				
Mount. zone	*	D	**P**	**A**	Insolation	∪	**D**	**P**		Horse (area)	↓	**D**	**P**	**A**
Humidity	↑			A	C	∩	D			Disturbance	↓		**P**	A
Na	↑			**A**	Mg	∩	**D**							
Sand	↑			A	Silt	∪		P						

*: categorical variable, ∪:concave response, ∩: unimodal response.
D: *Discoleus aguirrei*, P: *Plagiodontes patagonicus*, A: *Austroborus lutescens dorbignyi*, V: *Ventania avellanedae*
Only responses with p<0.15 depicted according to chi-square tests. **Bold:** sigificant responses at p<0.05. **Underlined:** responses with p<0.01

Table 5.9. Generalized responses of land snail species to environmental variables at plot level, according to corrected frequencies.

	Positive responses		CPA	RPA	Unimodal and concave responses		CPA	RPA	Negative responses		CPA	RPA
Habitat structure	rocks	↑	**D** V	**D P A V**	vegetation	∩	**D** V	**D P A** V				
	veg-3	↑	**P**	**P**	veg./rocks	∩	**D** P **A V**	**D P A V**				
	rocks-1		**A**		veg-1	∪	D A					
	rocks-2	↑	D	D	veg-2	∩	D P	D P				
	rocks-3	↑	**D P A V**	D **P A V**	veg-3	∩	**D**	**D**				
	shrubs	↑	**D P A V**	**D** P A V	rocks-1	∩	D					
					rocks-4	∩	**D V**	**D**				
					grasses	∩	**D P A V**	**D P A** V				
Floristic Composition	*G. ventan.*	↑	**D P A V**	**D P V**					g02	↓	D	D V
	g01	↑	**D P A V**	**D** P A **V**					g14	↓	**P A**	P
	g03	↑	A						g15	↓	A	**P A** V
	g04	↑	**D A**	**D**					g22	↓	**D** P	D
	g06	↑	**A**	**A**								
	g10		**D** A	D P								
	g11	↑	**D**	**D** A								
	g12		**D V**	P V								
	g20	↑		V								
Index	Fissures	↑	**D**	**D** P	Insolation	∪	**D** P	D	Disturbance	↓	**P** A	A
									Horse (plot)	↓	P	
Soil	C/N	↑	**D**		C	∪	A		Clay	↓	P A	P
	Na	↑	D **A**		N	∪	**D A**					
	Sand	↑	D		Mg	∩	V					
	Text. class	*	**P**	P	Silt	∪	**D P A**	**D A**				

*: categorical variable, ∪:concave response, ∩: unimodal response
D: *Discoleus aguirrei*, P: *Plagiodontes patagonicus*, A: *Austroborus lutescens dorbignyi*, V: *Ventania avellanedae*
Only responses with p<0.15 depicted according to chi-square tests. **Bold:** p<0.05. **Underlined:** p<0.01
CPA: Complete plot analysis, RPA: Restricted plot analysis. For more details, see text.

Figure 5.5. Corrected frequencies for mountainous zone, Sampling Area Analysis (SAA). Values >1 indicate preference, <1, rejection. Significant preferences or rejections for each mountainous zone are labeled with '*', calculated according to Gauthier *et al* (1977). *p* values below each species correspond to chi-square tests. Sm: summits of Sierra de la Ventana, Sl: slopes of Sierra de la Ventana, Lw: lowlands, CE: Cordón Esmeralda mountain range.

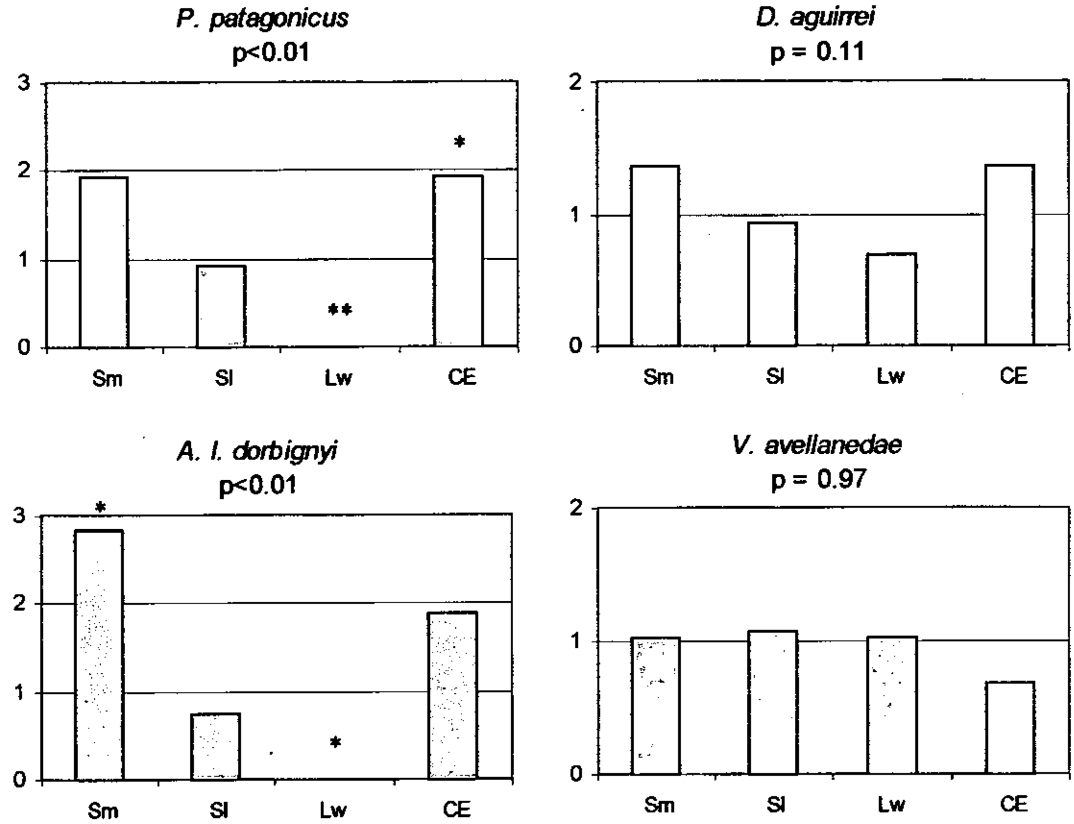
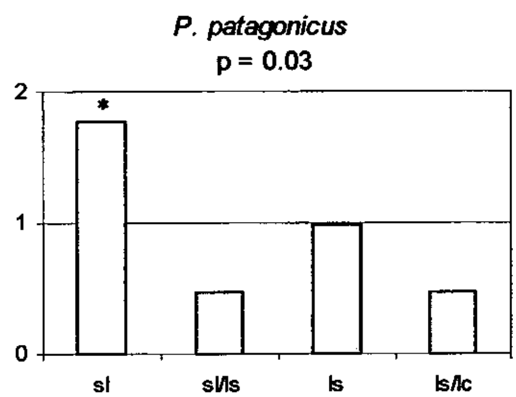


Figure 5.6 Response of *P. patagonicus* to soil textural classes (corrected frequencies): Values >1 indicate preference, <1, rejection. Significant preferences or rejections for each mountainous zone are labeled with '*', calculated according to Gauthier *et al* (1977). *p* values below each species correspond to chi-square tests. **sl**: sandy-loam, **sl/ls**: sandy-loam/loam-sandy, **ls**: loam-sandy, **ls/lc**: loam-sandy/loam-clayey.

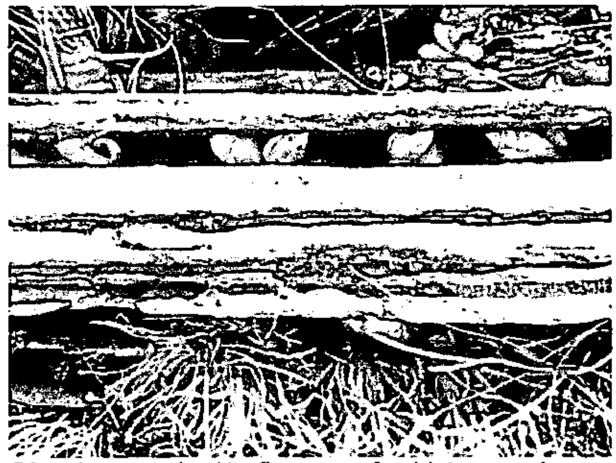


Discussion

The four land snail species studied showed no qualitative differences in the responses to single environmental conditions. Thus, the habitat of two species could not be neatly discriminated by any measured environmental variables. Further, the association indexes revealed positive relationships among land snails. Consequently, some of the results will be discussed considering all snail species together, though highlighting the important specific responses.

Among the results at sampling area level (SAA), we saw significant responses for *A. l. dorbignyi, P. patagonicus* and *D. aguirrei*, but not for *V. avellanedae*, possibly because of its low number of presences (table 5.9). The most significant generalized response to environmental variables at the sampling area level is the rejection to horse impact. The type of mountainous zone has also an important effect on land snail distribution. Summits of Sierra de la Ventana, and Cordón Esmeralda mountain range showed a high proportion of snail presences. Lower proportions of occurrences were observed in the slopes of Sierra de la Ventana, which did not show a homogeneous set of environmental conditions. Then, each case should be interpreted taking into account the responses to specific environmental conditions. Lowlands, where the effect of horses is most notable, presented a low frequency of snail occurrences. Particularly, *A. l dorbignyi* and *P. patagonicus* were not recorded in this area. Soil variables and climatic indexes were not so generally important, depending on the species. One must be cautious with the computed absences of the less abundant species, *A. l. dorbignyi* and *V. avellanedae,* at sampling area scale, because uncertainity of species absence at this geographical scale. At any rate, our computations as absences can be interpreted as indicating either low abundance or absence of snail's species.

The most remarkable generalized response in the complete plot analysis (CPA) is the highly significant preference for the endemic shrub *Grindelia ventanensis*. Notwithstanding, this plant -even being a good predictor of snail presence- occurs in only 13 plots of 125; therefore, it accounts for only a minor fraction of snail presences. The variables that describe the cover structure of the habitat are also important, and there are significant responses of several snail species to most of them. Since these are cover percent variables, they are strongly correlated. Consequently, the responses of land snails to different cover variables are also correlated. The set of variables that had the greatest effect at microgeographical level (RPA: Restricted plot analysis) are the habitat structure variables. In each sampling area we deliberately selected plot locations in diverging habitats, which usually represented sites showing quite distinct habitat structure features, as rocky *vs.* non-rocky habitats. The response of snails to such diverging habitats (for example snails usually preferred plots with rocks) contributes to the importance of habitat structure variables at a microgeographical scale. In this analysis the most important variable was vegetation/rocks ratio. The importance of the responses to floristic groups and the environmental variables derived from them (disturbance, climate, and fissures) depends on the species. The same applies to soil variables. We saw that the effect of chemical soil variables is not so important at a microgeographical scale, given that there are few significant responses in the RPA.

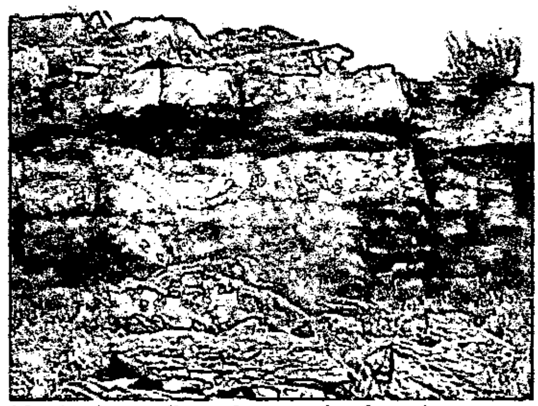

Discoleus aguirrei in fissures of schistose rocks

Sampling was conducted in conditions of no rain, so snails were found inactive. Seasonal and daily migrations are important in some land snail populations (Lind, 1988; Pollard, 1975). This can have important consequences on the choice of resting sites. Therefore, by visiting each plot only once and in a single season, we may have a partial and biased result. However, the microhabitats where living snails were found are expected to give hints of the major resting sites of snails and of their relative importance, at least in spring-summer seasons. *Ventania avellanedae* was the species whose microhabitat was more related to rocks. Almost 75% of the living snails were found directly associated to rocks, and more than 50% were found specifically in fissures. Some were found attached to vegetation, but generally these plants occurred in plots containing rocks. *Discoleus aguirrei* occupied the same habitats as *Ventania avellanedae*. *Grindelia ventanensis* was the item that supported the greatest snail densities of *D. aguirrei* and *P. patagonicus,* in spite of having found only four times associated to the shrub. *Plagiodontes patagonicus* was not found in fissures. There were differences in the resting sites of snails found under rocks. *Plagiodontes patagonicus* were found usually half buried into the soil, whereas *Ventania avellanedae* and *Discoleus aguirrei* were more frequently attached to the rocks.

The differential use of rocks among species can be analysed in terms of shell form. Several works studied the relationship of snail morphometric characteristics and habitat, in several regions of the world and with various different approaches (*e.g.* Cain 1977, Cameron 1978a, Cain, 1978; Solem & Climo, 1985; Winter & Gittenberg, 1998). In particular, Heller (1987) conducted a detailed study of the relationships between resting sites and shell characteristics in a Mediterranean arid environment, and interpreted his results in adaptive terms. He found that rock-dwellers have usually an elongated shell that facilitates manoeuvring and fit into narrow fissures or crevices. Conversely, ground-dwelling snails with burrowing habits require a big strong foot. Hence, they present a globose, big-mouthed shell, in order to accommodate such a foot. Bush-dwellers have general shell characteristics similar to ground-dwellers, while litter-dwellers show a minute size, no matter their shell form.

Austroborus lutescens dorbignyi has a typical globose, big-mouthed shell, and a strong foot of considerable dimensions, characteristics of ground-dwellers with burrowing habits. The two occasions that we found living specimens in this study could be reflecting a low abundance of this species. However, as empty shells are common, it is likely that a more thorough search, *e.g.* burrowing into the soil, was necessary to find more living specimens. Hence, many could have been overseen. Doering (1881) thought that the difficulty of finding living *A. l. dorbignyi* was related to its burrowing habits. Further observations in the area revealed living specimens burrowed into the soil under stones, but never attached to rocks.

Ventania avellanedae presents the opposite shell characteristics: a narrow, elongated, multi-whorled shell, typical of rock-dwellers. In fact, this was the species more associated to fissures (figure 5.2). This is an endemic species, restricted to mountainous environments of Sierra de la Ventana, while the other three studied species are also found in environments of the surrounding Pampa plains. Rocks in the surrounding plains are scarcer than in the mountainous region and they have clear differences in physical characteristics. They are of low height, and present no fissures or crevices, offering poor shelter to typical rock-dwellers. *Ventania avellanedae* might have such a strong dependence on rocky environments, as suggested by the habitats reported and shell characteristics, that limits its distribution to the Ventania Mountains.



Ventania avellanedae can be found attached to such high rock walls

Plagiodontes patagonicus and *Discoleus aguirrei* have a shell of intermediate shell length/diameter index. But, while *P. patagonicus* was never found in fissures, this is a common habitat for *Discoleus aguirrei* (figure 5.2). These species have a considerable difference in shell weight despite its similar size, that of *P. patagonicus* being 3,5 times heavier than *D. aguirrei* (*P. patagonicus*: 0.57g, *D. aguirrei*: 0,16g, n=10 for both species). This heavy burden could be an important limitation for travelling long distances on vertical surfaces, which is, in most cases, a necessary condition for reaching fissures. Differences in resting sites of similar-shaped shells of distinct weights have been reported for *Helix* species (Heller, 1987). *Helix aspersa*, which has a lighter shell than other *Helix* species, is commonly found attached to vertical surfaces at high altitudes, a behaviour that was not reported for their heavier allied species. Moreover, *D. aguirrei* is found much more tightly adhered to rocks than *P. patagonicus*. This, added to the differences in shell weight, could explain why *D. aguirrei* is found more frequently adhered to high vertical rock surfaces and in fissures –similar to *Ventania avellanedae*- than *P. patagonicus*.

The presence of rocky outcrops seems to be an important microgeographical habitat requirement. All species rejected sites without rocky outcrops; the few inhabited plots that did not contain rocks corresponded to the summits, where they were associated to the shrub *Grindelia ventanensis*. Various workers have recognized the importance of rocks as shelter for land snails. Some desert snails are known to aestivate under rocks (Dillon, 1980;

Wiesenborn, 2000), a microhabitat capable to retain more humidity than the exposed surroundings during dry climatic conditions. Giokas & Mylonas (2002) and Heller (1987) also pointed out the importance of crevices and fissures as aestivating and resting sites for some rock-dwelling snails of arid and semi-arid environments. As early as 1880, Aguirre observed that fissures of rocks in the southern Pampas mountains might provide adequate shelter. Snails attached to vertical rock surfaces are probably out of reach for predators that live on the ground, like small rodents, which are common predators of land snails. A better protection could be offered by fissures, where snail are less visible and out of reach for predators because of the narrow openings of these shelters. Direct sunlight, and consequently high temperatures and desiccation, can be avoided at the shadow of vertical surfaces, and especially, in fissures.

The response to vegetation is unimodal. The decrease of preference or the rejection of high values of vegetation could respond to the fact that the higher the cover of vegetation, the lower the cover of rocks. In spite of the importance of rocks, snails are usually absent from places where rocks clearly dominate the substratum at the expenses of vegetation cover. The variable vegetation/rocks ratio, showed a preference for intermediate covers, where neither vegetation nor rocks dominate over each other. Probably the most notable cases are plain bedrocks occurring at high altitudes in slopes and in some summits of Sierra de la Ventana mountain range. Such riparian environments offer little shelter in the form of fissures, crevices. They have thin, non-developed soils, and consequently support scarce vegetation, dominated by lichens (Frangi & Bottino, 1995; Kristensen & Frangi, 1995). Plant material is the major food source of most land snails (Speiser, 2001). Therefore, vegetal cover should be present in some quantities to assure enough food. The occurrence of some vegetation cover is also an indicator of soil presence, which is important for burrowing species and for egg laying (Tompa, 1984). *Plagiodontes patagonicus* lays eggs in small holes burrowed into the soil, under stones (pers. obs.). In summary, both vegetation and rocks appear to be important.


Snails are absent from such extense bedrocks, with almost no soil or plants

All species preferred shrubs, and the response to grasses was unimodal. These results can be interpreted in terms of rock and vegetation cover. Shrubs are slightly positively correlated to the preferred rocks (r_s=0.23, $p<0.05$); the cover of grass, the dominant physiognomy in the area (Frangi & Bottino, 1995), is strongly correlated to vegetation, which shows a generalized unimodal response. Thus, such similar responses are expected for the observed relationships among variables. Other reasons may contribute to the observed responses to grasses and shrubs. Grasses in these Pampa mountains are dominated by gramineae, a type of vegetation generally avoided as food source by land snails (Speiser, 2001). Gramineae are usually tough, with a high content of silica in the leaves, characteristics that probably explain their rejection as food (Speiser, 2001; Iglesias & Castillejo, 1999; Chang, 1991). In general terms, shrubs might offer better shelter or food source than gramineae. Ferns were found in low abundance, and we failed to find any meaningful response of land snails.

An analysis of the responses to mesoclimate and soil chemical variables, which have a considerable range of variation, suggests that many of these variables, even having meaningful responses, are not important limiting factors. Firstly, the mesoclimate and soil variables considered are strongly interrelated and showed a clear regional pattern of variation. Hence, these responses are rather redundant, and a single explanation might account for all the responses. Secondly, the variables insolation, total nitrogen and sodium appear not to be limiting, for the response curves are concave, that is, extremes values are preferred and intermediate values rejected. Thirdly, and finally, even when *A. l. dorbignyi* showed a preference for higher values of humidity and sodium, this species was nevertheless frequently found in Cordón Esmeralda, a region with low values of humidity and sodium. In lowlands and slopes of Sierra de la Ventana, low sodium and humidity sites have a high horse impact. Therefore, we consider that a primary rejection to sites with horse impact, with a secondary correlated response of soil and climatic conditions, is a more straightforward explanation than considering humidity and sodium contents as limiting factors in Sierra de la Ventana but not in Cordón Esmeralda.

Although climatic conditions seemed not to be limiting, they appeared to have an influence on the abundance of *Plagiodontes patagonicus*. Many of the most humid and less insolated samples where *P. patagonicus* were found, contained only a single dead specimen, as was seen in the analysis excluding such low abundance samples from the set of presences. This suggests that in such conditions, *Plagiodontes patagonicus* is an occasional species. Probably this is a direct response to low temperature, rather than to high humidity, though other correlated factors independent of climate cannot be excluded. Certainly, more sampling effort in such humid and low insolated sites would be necessary to disentangle the effect of these factors.

In the literature, climatic factors are considered to play a central role in the distribution of land snail (Boycott, 1934; Bishop, 1977b). Gradual changes in temperature, precipitation or humidity are considered one of the major determinants on the variation of snail faunas across altitudinal gradients (Labaune & Magnin, 2001, 2002; Tattersfield *et al.*, 2001; Coney *et al.*, 1982). On a local scale, contiguous slopes of different aspect can have marked differences in climatic conditions, due to differences in insolation. Influences of climatic conditions on such small scale are reported as having important consequences on the distribution pattern of Helicids (Grime & Blythe, 1969; Harvey, 1974; Pollard, 1975). Considering this importance, is rather remarkable that climatic factors did not seem to play a key role in the study area, where the changing topography and substratum allow the occurrence of manifest distinct local climatic variations, termed 'mesoclimate' by Kristensen & Frangi (1995, 1996). This seemingly independence of climatic conditions could be associated to the ability of land snails to select habitats with favourable microclimatic conditions, provided the environment is sufficiently heterogeneous. So, land snails might rely more on the availability of adequate microhabitats rather than on the prevailing mesoclimatic conditions. In a mountainous environment with a single vegetation stratum dominated by grasslands, rocks appear to be one of the clearest sources of heterogeneity. Fissures can provide protection in high insolated sites, and soil under rocks can have beneficial climatic characteristics, such as a lower temperature and better humidity retention than the surrounding soil, as was discussed earlier. The influence of rocks on microclimatic conditions can be a reason for the widespread preference of rocky sites.

An approach taken in many regions forests is to relate land snail faunistic composition, distribution pattern and abundance with 'habitat types' defined in terms of plant communities (Bishop, 1977a; Ports, 1996; Karlin, 1961; Wäreborn, 1970; Kralka, 1986; Cameron, 1986). Forests represent usually a more or less uniform set of environmental conditions, so noticeable relationships with snails are expected to arise. There are great variations in floristic composition in Sierra de la Ventana when we compare areas showing extreme diverging climatic conditions. This allows the establishment of a diverse flora, with many endemisms and components characteristic from distant phytogeographical regions. For example, slopes of high elevation and southern aspect in Sierra de la Ventana, present conditions of low insolation, high humidity and low temperatures, where plants of narrow ecological tolerance, including flora components typical of the cold Patagonian Andes forests, grow. At the other extreme, flora of the highly insolated northern aspect slopes has exclusive components, as well as plant species of the austrobrazilian region (Kristensen & Frangi, 1995; Frangi & Bottino, 1995). Therefore, a distinctive flora occurs when we consider areas showing extreme climatic conditions in Sierra de la Ventana. But, as seen before, climate does not appear to have a major influence. Each snail species showed preference for at least two groups that indicate diverging climatic conditions, *e.g.*, preference for at least one of the groups of moist, fresh or shadow conditions (G1, G3), and also preference for groups that indicate insolated or dry conditions (G10, G11, G12).

Vegetal communities of extreme climatic conditions have a unique and neatly defined species composition. However, over large areas of Sierra de la Ventana community composition does not show such clear limits. In many cases species composition of the communities described by Frangi & Bottino (1995) overlap considerably, and most of them are not dominated by one or few species. The NE and SW slopes of Sierra de la Ventana, lowlands and Cordón Esmeralda, which occupy the major surface in the mountains, do not show such marked variation of climatic conditions (Kristensen & Frangi 1996), the floristic composition being transitional with a mix of components (Kristensen & Frangi, 1995). So, throughout wide extensions floristic composition varies in a complex and intricate pattern, probably reflecting the complexity of habitat variations at a smaller geographical scale. Therefore, it is difficult to study snail relationships with 'habitat types' defined in terms of plant communities over large areas in Sierra de la Ventana, an approach taken in many regions with forests (Bishop, 1977a; Ports, 1996; Karlin, 1961; Wäreborn, 1970; Kralka, 1986; Cameron, 1986). Habitat and plant species composition varies notably when contrasting rocky outcrops with their nearby non-rocky surroundings, in a microgeographical scale.

We found several positive and negative responses of land snails to floristic groups, which can be related to the ecological conditions in which they occur. Floristic composition is not believed to be a limiting factor in snail distribution. Associations with floristic composition are usually believed to arise from responses to other correlated factors, as to the climatic conditions in which they occur, the microhabitat conditions created by plants or to the physiognomy of the vegetation (Grime & Blythe, 1969; Bishop 1977b). Additionally, most snails are considered food generalists, feeding on a wide variety of plant species, especially decaying vegetation (Speiser, 2001; Grime & Blythe, 1969; Chang, 1991; Hatziioannou *et al.*, 1994) what can explain the wide occurrence of snail across different environments.

The two environmental conditions derived from plant information that had the clearest response by land snails are the preference for fissures and the rejection of plant species indicating conditions of disturbance. *Discoleus aguirrei* and to a minor extent *P. patagonicus* showed a meaningful response to fissures. *Discoleus aguirrei* was found in fissures, and the preference for this index probably is also reflecting this behaviour. *Ventania avellanedae* was the species that had a greater proportion of specimens found in fissures but, given its low number of occurrences, a significant response to this index might not be detected. Instead, *P. patagonicus* was not recorded in this study in fissures, but there is some evidence for preference for fissure index in RPA. As the presence of fissures obviously depends on the presence of rocks, both variables are interrelated (r_s= 0.61, $p<0.01$). The response of *P. patagonicus* in this case might simply reflect the preference for rocks at a microgeographical level.

Floristic groups that indicate conditions of disturbance and overgrazing, G14 and G15, are rejected, and also the index of disturbance, which is related to horse impact (r_s= 0.28, $p<0.05$). The species more affected were *P. patagonicus* and *A. l. dorbignyi*. These two species were also not found in lowlands, which has the greatest impact of horses. The impact of horses will be discussed in detail below.

We have recorded living snails resting on a wide variety of plants, of different physiognomy and taxonomic groups, *e.g.*, on grasses, gramineae, shrubs. Some authors suggest that snails are found resting mainly on the plants they eat (Grime & Blythe, 1969), but Hatziioannou *et al.* (1994) say that they are simply found attached to the most abundant species, which in some seasons are also the plants preferred as food. It is generally accepted that the specific floristic composition is not determinant on the distribution of land snails, since the great majority of snails are food generalists, eating principally decaying plants (Speiser, 2001; Chang, 1991; Grime & Blythe, 1969). Nevertheless, some plants are clearly rejected, for physical characteristics, low nutritive value, or deterrent secondary compounds, while others are preferred (Grime & Blythe, 1969; Speiser, 2001; Hatziioannu *et al.*, 1994; Chang, 1991; Iglesias & Castillejo, 1999). As a consequence, plants can affect local distribution pattern and snail population density (Grime & Blythe, 1969; Iglesias & Castillejo, 1999).

The most notable case of positive relationship with plants in our study is the association of snails with *Grindelia ventanensis*, a tiny endemic shrub that occurs at high elevations (Kristensen & Frangi, 1995; Frangi & Bottino, 1995). The highest densities of *P. patagonicus* and *D. aguirrei* were found under this shrub, in summits, where this plant is most abundant. This plant was the only habitat where living *A. l. dorbignyi* were found. *Ventania avellanedae* was the snail less associated to this habitat, which agrees with its shell characteristic of rock dwellers. Snails choose this shrub because it possibly offers adequate shelter and food, or because it co-occurs with other environmental variables beneficial to snails. In certain summits the association with this shrub was clear: the snails only appeared under these bushes, and not in the surrounding low grassland matrix. This happened even in places with no rocks nearby- habitat recognised as an important resting place for snails-, suggesting that this shrub might provide a good substitute shelter. Some structural characteristics of this plant seem to support this claim. This domed dwarf evergreen shrub presents in its exposed surface, a continuous layer made up of tightly-aggregated and tough leaves that might provide good protection against insolation and wind, an especially important adaptation for living in summits where these and other stringent climatic conditions occur (Kristensen & Frangi, 1995, 1996). Besides, the vegetation surrounding this shrub usually consists in a matrix of low grasses due to the extreme climatic conditions (Frangi & Bottino, 1995; Kristensen & Frangi, 1995, 1996) sometimes reinforced by some grazing.

Snails under *Grindelia ventanesis*

In this context, *G. ventanensis* represents the greatest vegetal biomass, being probably the major food source in the area. The senescent stems and leaves that accumulate beneath the exposed layer of living leaves could supply enough and adequate food. . Other food material to support such high densities seems unlikely. Other aspect of this plant that might contribute for snail preference is that it occurs in sites with a rocky layer beneath the soil that prevents percolation, so soils are humid for prolonged periods of time. Plants supporting high snail densities are reported by some authors. For example, *Urtica dioica* -which sometimes supports high snail densities (Grime & Blythe, 1969; Cain et al., 1990; Hatziianou *et al.*, 1994)- is believed to offer both high food quality and adequate shelter (Iglesias & Castillejo, 1999). Something similar might be happening with *Grindelia ventanensis* and land snails in Sierra de la Ventana.

The endemic shrub *Grindelia ventanesis* in summits

Considering the above-mentioned points, it seems very likely that the presence and high abundance of *P. patagonicus*, *A. l. dorbignyi* and *D. aguirrei* in summits is due to the presence of *Grindelia ventanensis*. However, we saw outside the study area, other summits with no *Grindelia ventanensis,* which supported nevertheless high densities of *P. patagonicus*, occurring almost exclusively (obs. pers). So, there could be factors other than *Grindelia ventanensis* playing a role, accounting for such high abundance in summits, at least for *P. patagonicus*.

Elsewhere in Sierra de la Ventana, snail populations might be limited by the availability of shelter –against drought or predation- or by the amount or quality of food, resources that could be offered in greater amount in summits.


Shells with signs of predation in the nest entrance of an unknown predator

Predation is known to affect strongly the distribution pattern and population density of both preys and predators. Boycott (1934), in his classic and influential publication, assigned a minor role to predation in determining abundance or distribution of snails. However, subsequent studies have shown that predators can have a great impact on the distribution pattern of land snail abundance (Yom-Tov, 1970; Mordan, 1977; Abramsky *et al.* 1990, 1992). Common predators of land snails cited in the literature include birds, small mammals -especially rodents-, and beetles larvae (*e.g.* Reichardt *et al.,* 1985; Deisler, 1987). Except for the lizard *Prisitidactylus casuhatiensis*, a specialist predator of land snails (Cei, 1993), and for the skunk *Conepatus chinga*, which occasionally includes snails in its diet (Manfredi *et al.*, 1997), natural predators of snails are unknown in Sierra de la Ventana. Based on field observations, we suppose that other predators could have great impact on land snails. It is common to find shells with signs of predation, both isolated perforated shells, and also cumulus of shells with signs of predation in the opening of nests under stones that might belong to rodents. Abramsky *et al.* (1990) showed that the distribution of abundance of two rodent species predators of land snails, could explain the variation of densities of the desert snail *Trochoidea seetzenii,* and that the population of predators were limited by the availability of refuge. By increasing experimentally the number of rodent shelters, Abramsky *et al.* (1992) confirmed that abundance of the desert snail decreased as the abundance of the predator increased. In Sierra de la Ventana, it looks likely that the extreme climatic conditions and the 'few ecological residences' offered by summits (Kristensen & Frangi, 1995, 1996) might have a negative effect on the distribution of snail predators. Assuming the latter, and that predation is important elsewhere in the mountains, the high abundance of snails in an apparently unfavourable habitat could be explained: summits could be a more adverse habitat for their predators than for the snails themselves.

Soil conditions in Sierra de la Ventana are poorly studied (Frangi & Bottino, 1995). Although all the soil material of Sierra de la Ventana has the same origin (Vargas Gil & Scoppa, 1973), we found that some of its properties show a considerable regional variation, probably due to the effect of rock material from different geological origin (Vargas Gil & Scoppa, 1973) and differences in climatic conditions. In general, the more dry and insolated the area, the less acidic is the soil, and the contents of carbon, nitrogen and sodium are lower. These conditions are typical of lowlands and Cordón Esmeralda.

Although soil properties are considered as important determinants in land snail distribution (discussed in Ondina *et al.*, 2004), they might not be so informative in our study. We saw that some of the meaningful results to soil chemical variables have concave response curves, and that meaningful relationships could be correlated to other primary causes, as the preference for sodium by *Austroborus lutescens dorbignyi*. However, there could be some trends suggested by the preference of *Discoleus aguirrei* for higher values of C/N, and the non-significant tendency of *Ventania avellanedae* to prefer intermediate values of magnesium. Additionally, textural properties appeared as important for *Austroborus lutescens dorbignyi, Plagiodontes patagonicus* and *Ventania avellanedae*. We have not found meaningful responses to pH and calcium, which are generally considered among the most important soil variables for land snails (Boycott, 1934; Burch, 1955; Cameron & Greenwood, 1992; Outeiro *et al.*, 1993; Ondina *et al.*, 2004; Hermida *et al.*, 2000; Ondina *et al.*, 1998; Wäreborn, 1970).

The edaphic factor pH is particularly important in studies that cover large areas and ranges of variation. Perhaps they were too small to detect a response in our study. Additionally, many soil variables are rather redundant and some significant responses are regarded as having indirect effects on land snails (Bishop, 1977 b); pH is generally related to other habitat features as edaphic factors and vegetation characteristics, which sometimes are believed to be the primary cause of snail's response, being pH possibly secondary correlated (Bishop, 1977b; Burch, 1955).

Calcium availability is considered as an important variable for terrestrial molluscs distribution (Boycott, 1934; Cameron & Greenwood, 1992; Burch, 1955; Outeiro *et al.*, 1993; Ondina *et al.*, 1998; Hermida *et al.*, 2000), and has clearly important biological functions for land snails. Calcium is the most important element of the shell, and it is important for reproduction and other physiological processes (Wäreborn, 1970).

In some cases, the calcium content of the litter, rather than the soil content, is cited as important for explaining land snail distribution (Bishop, 1977a; Ports, 1996), but both contents are interrelated and the importance of litter particularly applies to small-sized litter dwelling snails of forests (Ondina *et al.*, 2004), not studied here. Aguirre (1880) tried to explain the patterns of occurrences of molluscs in Sierras de Tandil -the nearest low mountain system to Ventania- based on the availability of calcium. He observed that many regions of the mountains had conditions seemingly adequate for the thriving of molluscs, but they were nevertheless uninhabited. Instead, snails appeared in areas with limestone. These observations were made for *Succinea magellanica* and for other unknown snails, that surely included *Discoleus aguirrei*, still undescribed at that time. This suggests that calcium availability is variable and might be a limiting factor for snails in the Pampas Mountains. Other hint for the possible importance of calcium was the common presence and high abundance of *Plagiodontes patagonicus*, which has a solid and heavy shell, in sites with abundant limestone outcrops at the riverbanks of the southwestern plain Pampas (Doering, 1881; pers. obs.). In general, the more humid the climatic conditions are, the deeper the limestone layer; the mountains of Sierra de la Ventana have more humid conditions than the surrounding plains (Paoloni *et al.*, 1988), so calcium in mountainous areas could be more limiting. Moreover, the rocks of the mountains of Sierra de la Ventana are metamorphic, poor in calcium. In spite of the variability of calcium content in Sierra de la Ventana, none of the studied species seems to be limited by soil calcium in the study area. A behaviour observed in *Plagiodontes patagonicus* suggests a mechanism that might account for a relative independence from soil calcium content. In several occasions, *P. patagonicus* were seen with their foot protracted over empty shells, probably as a way of getting calcium (pers. obs.).


Typical schistose rock outcrops of Cordón Esmeralda.

Textural features of the soil had certain importance on land snail distribution. Silt showed a bimodal response, being usually the intermediate values of silt fraction rejected. This odd response can be interpreted considering the regional distribution of silt. Intermediate values are common in lowlands, which have low proportion of snail presence. Sand and clay fractions do not show a regional pattern of variation, as silt fraction does. *Plagiodontes patagonicus*, *D. aguirrei* and *A. l. dorbignyi* showed a tendency to prefer higher values of sand fraction and lower values of clay conditions, *i.e.*, coarser textural conditions. Many studies have recognized an important effect of soil texture over land snail distribution. It seems that some species require coarse textural conditions for burrowing; so, clay dominated soils could bear an impediment to burrowing species (Hermida *et al.*, 2000). In this context, the most affected species might be *A. l. dorbignyi* followed by *P. patagonicus*. In this study we only detected a tendency that could be the result of the relative low variation of textural class fractions when compared to other studies. Soil in Sierra de la Ventana is predominantly sandy; the lowest content of sand was 60%. It remains the question if this habitat feature could pose limits of distribution considering a greater textural variation at a wider geographical level, at least for the burrowing species, *A. l dorbignyi*. In fact, Doering (1881) observed that this species had important burrowing habits and we did find it in sandy locations.

One of the clearest regional effects on land snails is the rejection of lowlands. The few sampling areas of the lowlands inhabited corresponded to transition regions to Cordón Esmeralda or to slopes of Sierra de la Ventana. As this area shows the highest horse impact, the question arises: are horses the major responsible for snail absence from lowlands, or could there be other measured or unmeasured variables important? Among the measured variables, mesoclimate and most of the chemical soil factors had a regional pattern of variation and are thus candidates for important variables. But, as it was discussed above, they does not seem to be limiting, since Cordón Esmeralda had similar values for these ecological variables, and is a region clearly preferred by snails. Among the floristic groups, the lowlands have a greater proportion of the rejected groups 14 and 15 that indicate conditions of disturbance and overgrazing, correlated to the surely prime effect of horses.

These results must be considered with the caveat that some other unmeasured variables correlated to horses can also be important. Horses might prefer large meadows areas with a lower frequency of rocky outcrops, as in lowlands. We described the fine scale habitat structure and cover pattern, but not such larger geographical scale that should be necessary to describe this situation. A lower frequency of rocky outcrops means a lower frequency of potentially suitable habitats, as it was discussed above. In this context, the probability of rocky patches to be inhabited could be lower because of the long distance among them. This is an alternative explanation for the lower presence of snails in rocky outcrops of lowlands, but by no means an exclusive one. This and horses impact could be acting together, even synergically, giving a lower colonization rate and a higher extinction rate of rocky patches respectively.

Horse impact can arise directly from trampling, or indirectly, via a reduction of vegetal material by grazing. Horses drastically reduce the height of vegetation; this effect is clearly seen if one compares the high-elevated grasses of the exclosures with the low carpet occurring elsewhere in lowlands. Grazed places are characterised by a xerothermophil snail fauna (Boycott, 1934; Cameron & Morgan-Huws, 1975; Labaune & Magnin, 2002), so grazing affects local climatic conditions. Reduced grass height can mean less vegetal material available for food as well as an increase in land snail visibility and thereby of predation risk. Zalba & Cozzani (2004) observed in this area a greater sensitivity to predation over bird eggs in the soil of overgrazed areas as compared to that of exclosures; a similar effect could be acting on land snails. An adequate assessment of horse impact requires adequate replicate conditions. Unfortunately, the exclosures in lowlands were established relatively recently, in 1996. We have not found snails in the exclosures, but having a previous history of fifty years of horse grazing pressure, snail extinction in the area cannot be excluded. Moreover, recolonization from distant areas in land snails –organism with poor dispersal abilities- is unlikely. A way of assessing horse impact in lowlands could be to intend the introduction of snail populations inside and outside the exclosure and compare population size and persistence.

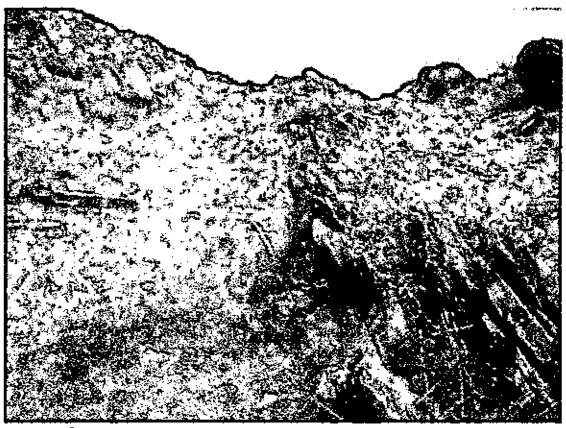
The geological composition of the rocks of lowlands and Cordón Esmeralda corresponds to formation Lolén. Rocky outcrops of Lolén geological formation consist in series of vertical or oblique parallel disposed layers of schistose rocks, creating narrow fissures and crevices between rock layers (Frangi & Bottino, 1995), where snail are found. Horses exert a greater impact on soil vegetation than in strips of rocky outcrops, which sometimes have considerably higher vegetation than the non-rocky grazed surroundings. In fact, the two species that seem to be more closely related to the soil, with burrowing habits and that do not use fissures as principal shelter source (*A. l. dorbignyi* and *P. patagonicus*), are the snails most affected by horses and disturbance. Actually, we saw that in lowlands *V. avellanedae* and *D. aguirrei* rested almost exclusively in fissures. Cameron (1978b) found that grazing affects more soil and litter species than species associated to rocky environments.

Horse impact could be a direct cause of absence of snails in places where horses are abundant. Horses could be imposing constant impact on land snails, so increasing its effect over time. Moreover, horse population is growing (Scorolli, 1999) posing an even worse perspective to the future.

Cordón Esmeralda is an area clearly preferred by land snails. Two effects are likely to be acting: zero horse impact, and a favourable habitat structure as regards to rock cover. The schistose rocks of Lolén geological formation offer numerous fissures and shelters. Detached rocky layers on ground are common, creating numerous shelters for burrowing species, as *Austroborus lutescens dorbignyi*. The pattern of rocky outcrops is more or less uniform and evenly distributed; there are no large areas covered mostly by rocks or without rocks, as it is possible to find in hillsides of Sierra de la Ventana.

Plagiodontes patagonicus under stones in Cordón Esmeralda

We did not detect an important role of the topographic features altitude and slope angle in the distribution of land snails. The effect of topography is generally considered as important, because it covaries with other biological important, often unmeasured, variables for land snails. Topography plays an important role on climate determination in mountainous regions (Tattersfield *et al.*, 2001; Labaune & Magnin, 2001; Coney *et al.*, 1980), as in Sierra de la Ventana (Kristensen & Frangi, 1995, 1996), and climate exerts a great influence on land



Cordón Esmeralda provides inter rock fissures and interstices, as well as rocks on the substrate snail distribution and abundance. The importance of slope has been related to the primary effects on land snails of the underlying rocks structure, and climatic correlations (Coney *et al*, 1980). The effect of topography has not a readily interpretation, it depends on each specific case, making it difficult to compare different works. For example, the greater the altitude, precipitation could be higher (this study) or lower (Tattersfield *et al.*, 2001). In the present study, climatic conditions were inferred by the information provided by plants, independently of topography. Climate did not appear as an important limiting feature. This can be a reason for not having detected an important response to topography. Other reason could be that regions of similar low altitudes - lowlands and Cordón Esmeralda- have habitat features that exert diverging effects on snail distribution.

Discoleus aguirrei was the most frequent species, and the one that seems to have the widest ecological niche or tolerance range to environmental variables. It is also the species which shows the highest number of significant responses, whereas *Ventania avellanedae*, with low presence, the one with lowest number of significant responses. The number of significant responses might therefore be related to the number of presences. *Ventania avellanedae* was always found in places also inhabited by *D. aguirrei*, what can be indicative of *V. avellanedae* having the same responses as *D. aguirrei*, but occurring in a lower frequency or abundance, or of *V. avellanedae* occupying a subniche of *D. aguirrei*. It is likely that part of the limitations of the distribution of *V. avellanedae* responds to the stronger dependence of rock resource, as was discussed above. The most notable difference in the distribution of *A. l. dorbignyi* and *P. patagonicus* as regards to the other two species is the absence from lowlands. *Plagiodontes patagonicus* and *A. l. dorbignyi* have relatively strong positive associations. However, while *P. patagonicus* is present in low abundance in very humid sites, *A. l. dorbignyi* shows a tendency to prefer sites with these conditions. Evidence for competition in these snails is missing. But some studies carried out on helicids showed that competition interactions can affect distribution patterns, and that local climatic conditions can affect the outcome of competition (Harvey, 1974).

In conclusion, rock presence seems to be an important factor in Sierra de la Ventana, probably as an important shelter. The requirement of rocks seems to be relaxed in summits, whenever the shrub *Grindelia ventanensis* is present in high abundance. The greatest abundances of *Plagiodontes patagonicus* and *Discoleus aguirrei* were observed associated to this shrub. *Discoleus aguirrei* is the most abundant species; other land snail species are usually associated to *Discoleus aguirrei*. Horses, or the correlated low abundance and frequency of rocky outcrops, possibly have a negative effect on snails, *Plagiodontes patagonicus* and *Austroborus lutescens dorbignyi* being the most affected. *Discoleus aguirrei* and *Ventania avellanedae* might be more resistant to horse impact for their use of fissures as shelter. Diverging resting microhabitats can be related to shell characteristics. Chemical condition of the soil does not appear to be important. Textural characteristics might be important, coarse textural conditions being preferred over finer fractions. This can be interpreted as better conditions for burrowing or egg laying. The climate conditions of humidity and insolation seems not to be important, though in the most humid areas *Plagiodontes patagonicus* are found in lower abundances.

6. PINES AND LAND SNAILS

A general description of pines' distribution pattern and its main impact in the reserve was described in chapter 1.

The assessment of pine impact on land snails has the problem of the absolute lack of historical data of presence and abundance of snails previous the establishment of pinewoods. Moreover, areas with and without pines may not be readily comparable, as they differ in other aspects not related with pines. Even the comparison of adjacent areas along the pines/no-pines border is difficult, since this is not a neatly defined limit. Pines show a scattered pattern of spreading, creating a complex mix of habitat types in this transition area, where pines could exert impact over time.

In the view of these considerations, one of the best assessment methods seems to perform extensive searches of snail populations under dense and long-term established pinewoods.

In this section we analyze the pattern of distribution of the four main macrosnails species *Plagiodontes patagonicus, Discoleus aguirrei, Austroborus lutescens dorbignyi* and *Ventania avellanedae* according to pine wood stands.

Methods

We searched snail populations along several transects across the extensive pine wood that lies in the soutwestern slopes of Sierra de la Ventana – where they spread upwards from the low elevation sites adjacent to the route, where they were originally implanted. We also searched snails in the southwestern slopes in areas with no pines, lying immediately above the pinewoods. This was a non-quantitative approach.

Pine effect on land snail presence was also analysed comparing more or less adjacent and similar rocky outcrops (which, according to the previous analysis, are the habitats with more abundance of land snails), located outside and inside the pine forest. Sampling points at the border of the pine forests were defined with the aid of satellite imagery, and transferred to the GPS. Land snail search was similar to the previous analysis (chapter 5).

Results

Five paired samples in pinewoods and areas with natural vegetation were taken. The only plot with recorded living snails was one located in natural grasslands -not under pines-, where two *Discoleus aguirrei* were found. Nevertheless, we found two old empty shells of *Plagiodontes patagonicus* below the dense needle litter in a plot under pine canopy.

Clearly, this data are insufficient for an assessment of pine impact. Finding replicate conditions for both kinds of habitats proved difficult, and much effort in sampling plots should be done to find differences with such kind of sampling procedure.

A clearer picture, with a more efficient effort, was seen in the results of the transects. We were able to find presence of snail population in the SW slopes above the line of trees, but never under the dense canopy of trees.

Discussion

While areas with recent pine invasions show a scattered pattern of pine distribution -intermingled with natural grasslands that could support snail populations- areas that have long-term invasions are clearly dominated by pines, where we did not found snail populations. Unfortunately, there are no data of previous presence of snail populations in these areas, but it is highly probable that over such large areas some populations occurred after the impact of pines.

The discovery of empty shells in stands of pines is not conclusive of previous snail presence, as the timing of shell degradation is unknown. The shell of *Plagiodontes patagonicus* is assumed to be long lasting because it is solid and heavy. Conversely, the light and fragile shell of *Discoleus aguirrei* is expected to degrade rapidly.


Virtually no plant grows under pine canopy

Pines produce a series of clear changes on the natural habitat, each of which could actually be affecting snail populations. Pines reduce sunligth radiation under the canopy, and soil properties undergo profound modifications in its chemical properties. In Sierra de la Ventana, Amiotti *et al.* (2000), recorded acidification of soils and leaching of calcium and other base cations produced by pines. These changes lead to a decrease in plant diversity and a replacement of natural grasses -unable to live under pine canopy- by exotic plants (Zalba, 2002). Areas with dense canopy support virtually no other plant species, being the soil and rocks covered by a dense layer of pine needles.

Content of calcium and other base cations, and pH, are important soil properties of the soil for land snails. In Sweden, studies revealed that changes related to soil acidification and base cation leaching lead to impoverishment of land snail abundance and diversity in forests (Gärdenfors, 1992; Wäreborn, 1970).

Conifer woods are known to support lower land snail abundance, diversity and species richness than deciduos forests (Karlin, 1961; Kralka, 1986; Cameron, 1986). The type of litter of conifers offers poorer conditions to land snails than deciduous forests (Cameron, 1986). Litter of conifer woods are poor in calcium (Coney *et al.* 1982), but other negative factors, as the content of resin in leaf litter, are also believed to contribute for a low quality of pine litter as food (Kralka, 1986). As plant diversity and cover under pine canopy also decreases, pines may not only offer lower quality, but also lower levels of food.

Concluding, pines seem to exert a clear negative effect on natural land snail populations, as they generally do on natural fauna and flora components of the Park. Nevertheless, the invasion in its first steps could have even positive consequences on snail populations. Scattered pines increase the heterogeneity of the landscape, thereby increasing the availability of microhabitats for land snails. Pines can create spots of shadow and humidity, and fallen logs and litter could offer moist microhabitats, providing more protection against direct solar radiation. However, the long-term outcome of the invasion is a reduction of habitat variability that eventually leads to a profound impact on natural soil biota and flora.

Pine control in the area is currently undertaken by the GEKKO group.

7. CONSERVATION OF LAND SNAILS: A DISCUSSION

The 'Ernesto Tornquist' Provincial Park protects a fraction of the local biodiversity hotspot represented by the Ventania Mountains in the Pampas region. This is not only an endemism-rich area, but also a region that brings together biota from diverse biogeographical regions, due to its diversity of climatic and environmental conditions. Regarding land snails, these mountains have so far three known endemic land snail species: *Ventania avellanedae, Zilchogyra franzi* and *Plagiodontes rocae*; here also do occur land snails present in natural environments of the surrounding plains: *Plagiodontes patagonicus* and *Austroborus lutescens dorbignyi,* and snails present in other small mountain systems, as is the case of *Discoleus aguirrei*. This diversity and abundance of land snails turns the Ventania Mountains into the single most important area for land snail conservation of the southern Pampas region, which has a poor diversity and abundance of land snails elsewhere in the plain Pampas.

Factors that could be considered *a priori* as threatening factors to land snails in the Park are the effect of introduced animals (especially horses), woody plants (especially pines), fires (some intentional fires occurred in the last few years in the Park), tourism and interactions with introduced land snails.

How efficiently does the Park protect local land snail diversity? Considering that possible impact factors -whether represented by cattle, spread of pines or whatever other cause might be- can not be adequately managed outside protected areas, this question acquires even more relevance, especially at long term periods. For answering this question, two aspects must be considered. First, not every endemic snail species occur in the Park. Second, this protected area is not free of factors that might have an impact on land snail populations.

Plagiodontes rocae is endemic to the mountains but occurs outside the Park, being probably restricted to the Curamalal mountain range, located farther north. In Curamalal mountain range there was also cited a certain *Discoleus curamalalensis*, endemic snail that was not found again ever since its first record. However, Miquel (1998) considered that the two specimens described as *Discoleus curamalalensis* are specimens of *Bulimulus rushii* whose collecting location was incorrectly labelled, being in fact not present at the Ventania Mountains. At any rate, at least the endemic *Plagiodontes rocae* does occur outside protected areas. It appears important to conduct surveys in the Curamalal mountain range to assess the actual distribution range and population levels of *Plagiodontes rocae*, to identify possible threatening factors, as well as to search for other snail species that could occur here. The Park might fail to adequately protect all the land snail diversity of the Ventania Mountains.

The other main four macrosnails -*Discoleus aguirrei, Austroborus lutescens dorbignyi, Ventania avellanedae* and *Plagiodontes patagonicus*- seem to be not threatened in the Park so far. They do not show restricted distribution, and they are found throughout the Park, being abundant in some places. There are large areas with populations of snails, like Cordón Esmeralda mountain range, or areas with high densities, as found in some summits of Sierra de la Ventana mountain range. However, long-term persistence surely depends on how efficiently and correctly conservation actions are taken in the Park, especially those regarding pine and horse management. Future is uncertain, at least for some local populations. The possible impact of horses and pines were discussed in chapter 5 and 6 respectively.

Pines are affecting mostly the SW slopes of Sierra de la Ventana, a population that is steadily spreading to higher altitudes. So, the main threat to snail populations at this area is the advance of pines. The small fraction of Sierra de la Ventana mountain range south of the route also has pines, but they occur in a scattered pattern and in low abundance. As snail populations in this horse-free area are frequent, and sometimes abundant, it is advisable to avoid the proliferation of pines in these early stages of the invasion. Summits, with high densities of *Plagiodontes patagonicus, Discoleus aguirrei* and *Austroborus lutescens dorbignyi* are far from being threatened by pines. Instead, horses do appear here, especially males that do not have a herd and are displaced to less favourable regions of the Park (Scorolli, pers. comm.). As horse population is increasing, so could also be the impact in these habitats that are so important for land snails. Perhaps snail populations of the Cordón Esmeralda mountain range are the safest in long-term periods, provided horse entrance to Cordón Esmeralda will still be avoided in the future, as it is now by the internal wire fence.

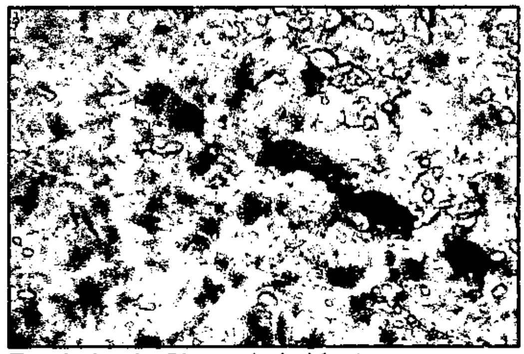
Zilchogyra franzi inhabits humid caves in gorges, an area that is not severely affected by horses. After a fire occurred in summer 2002-2003 that affected Sierra de la Ventana in the section of the Park south of the route, we found that fire reached the vegetation of humid caves with ferns. In two such caves, we found burned shells and no living exemplars. Fire might cause local extinctions of population patches of *Z. franzi.*

Ferns in the cave, recovering from fire, where *Zilchoavra franzi* was found

We saw that fire affected also macrosnail populations, killing many snails. However, this catastrophic event seems not to have strong long-term impact. After a year, many living snails were seen in the burned areas. Probably the rocks represented major refuges against fire, leaving enough survivors for population recovery. Kiss & Magnin (2003) studied the impact of fire on land snails communities and its recovery in Mediterranean habitats, and concluded that snail recovery procedeed mainly from survivors located in patches of habitats not affected by fire inside the burned area, and not from the unburned surroundings.

The 67 km^2 Park receives yearly the visit of thousands of tourists. Tourism could have negative consequences on land snails by the direct modification of the habitat caused by trampling. However, nowadays paths for trekking are well marked, being the tourist activities controlled and restricted to certain areas. Therefore, tourism appears not to be a major factor of impact on land snail populations. Also, competition with alien snails is presently not important in the Park. The introduced garden snail *Helix aspersa* is restricted to anthropic environments, where no autochthonous snails occur.

Even when macrosnails species seem not to be threatened nowadays, we suspect that local extinctions or decline in some parts of the Park could have occurred in these four species. Extinctions occurred almost certainly in places with old and heavy invasions of pines in the SW slopes, and probably in areas severely invaded by horses. A proper conservation means not only to assure the survivor of the species at a great scale, but also to preserve local populations. Land snail predators with restricted distribution might depend on the well being of local prey populations.

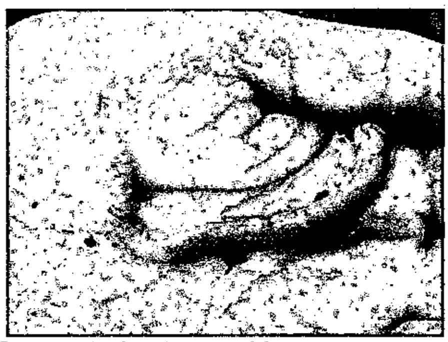

Feral pigs in Sierra de la Ventana, seen and photographed for the first time.

Therefore, the knowledge of factors affecting presence and abundance of land snails are important for sketching conservation strategies not only for land snails, but also for its natural predators. In this point, it is important to know the reasons for the decline of the endemic lizard *Pristidactylus casuhatiensis* –a specialist predator of snails, whose teeth are adapted to brake the strong shells of *Plagiodontes patagonicus* (Cei, 1993). There are no specific studies on the ecology or conservation status of this poorly known lizard, but there is consensus in that *Pristidactylus casuhatiensis* used to be common in the area, but that is very hard to find nowadays, to the extent to be considered now as the more threatened reptile of Argentina (Lavilla *et al.*, 2000). Human collections could have had a great impact in the past, and can still be important in the present, in the form of unauthorised collections. There were extensive early scientific collects, in moments when it was more abundant (Pérez, pers. comm.), and, recently, the Park rangers avoided that a tourist took away one *P. casuhatiensis* (Park rangers, pers. comm.). A diminishing number of preys could have enormous impact on specialized predators. But, as there is a complete lack of records of local population levels of the prey –the snails-, it is almost impossible to know whether this could be a cause of the decline. This lizard occurs at high altitudes; most of the latest records belong to 'Cerro Destierro', which have summits with the highest abundance of the snail *P. patagonicus* in the Park, and from 'Cerro Ventana' especially from an area of dense rocky outcrops near the concurred popular tourist path to 'hueco de la Ventana'. Nearby there is a population of snails, associated to some *Grindelia ventanensis,* in areas of moist soil. It is important to warn about the possible impact of the relatively newly introduced feral pigs, which create a new cause of concern in the Park (Park rangers, pers. comm.). Signs of their activity –removal of plants, leaving bare soil- were increasingly seen in the Park in the latest years (Park rangers and tourist guides, pers.

comm.; pers. obs.), and we had the opportunity to see and photograph them for the first time in the Park, near the mentioned area where snail populations and the lizard occur. Park rangers and tourist guides (pers. comm.) also saw recently signs of soil removal that affected this population of *Grindelia ventanensis*. It is necessary to take into account these effects, and to see how this could be presently affecting and affect in a near future, local population status of vegetation, snails and of the lizard *Pristidactylus casuhatiensis*. Boars are also known to predate on land snails, with catastrophic consequences on local populations (Heller & Ittiel, 1990). Strong control measures in early stages of this new invasion might avoid a greater impact in the future.

8. EARTHWORM DIVERSITY

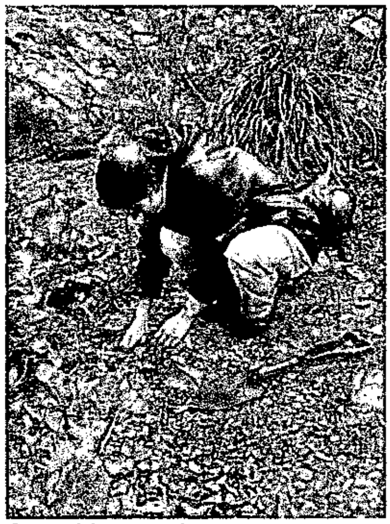
Records of terrestrial earthworms are actually scarce for Buenos Aires province (Ljungström *et al.*, 1975; Mischis, 2000), and almost non-existent for the Park. Burela & Cazzaniga (2001) have recently published the first earthworm assessment from the semiarid SW area of this province, including eight species, most of them world wide spread with predominance of species in the family Lumbricidae, which are more frequent in anthropized systems. Before the beginning of this project, S. Burela and N. J. Cazzaniga had only found *Octolasion tyrtaeum* and *Aporrectodea turgida* in the Bahía Blanca Mountain within the 'Ernesto Tornquist' Provincial Park.


Aporrectodea trapezoides

Methods

We have searched and collected earthworms under stones and dung, in mosses, and soil quadrates (20 x 20 cm) by digging up the soil and hand sorting; both in natural and modified areas (horse paths and woody forests). Taxonomic identification was done in the field (when it was possible) and at the laboratory according to Righi (1979) and Mischis (1991) taxonomic keys.

Our survey was focused only in megadrili group, worms that are large and mostly terrestrial excluding small and aquatic worms - microdrili- (Edwards & Bohlen, 1996).


Searching earthworms

Results

We found eight megadrili species: *Aporrectodea turgida, A. trapezoides, A. rosea, Octolasion tyrtaeum, Bimastos parvus* (Family Lumbricidae), *Eukerria saltensis, Belladrilus jimii* (Family Ocnerodrilidae) and *Microscolex dubius* (Family Acanthodrilidae). The five lumbricid species are exotic. *Eukerria saltensis* and *Belladrilus jimi* belong to a family thought to be aboriginal from South America, and *M. dubius* is a species of possible South American origin. All of them are nowadays part of the group of most widely distributed earthworms in the world (Edwards & Bohlen, 1996).

Family Lumbricidae

This family contains 20-30 species belonging to the genera *Lumbricus, Aporrectodea, Allolobophora, Eisenia, Eiseniella, Dendrobaena, Dendrodrilus,* *Octolasion*, and *Bimastos* that have been spread from Europe by man during the past few hundred years. Nowadays, they become dominant in agricultural lands and gardens throughout temperate regions of the world. Lumbricid species have the ability to adapt to new environments and live in those that are constantly disturbed by anthropic activities more than any other oligochaetes.

We give some general diagnostic features of the three major ecological groups proposed by Bouché (1977) for European lumbricids:

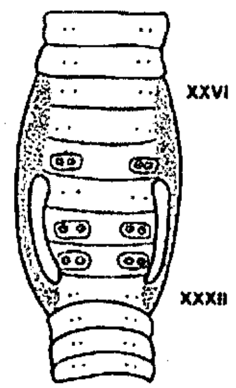
1) Endogeic species: worms that feed on decomposing litter with preference for material rich in organic matter; generally unpigmented or lightly pigmented; adult specimens are medium sized; they live in continuous and extensive burrows, usually in the upper 10-15 cm of soil; with a intermediate longevity and short generation time; they can enter in diapause in response to drought.
2) Anecic species
3) Epigeic species: worms that feed on decomposing litter on the soil surface and no ingest soil; are heavy pigmented (both ventrally and dorsally); adult specimens are small medium; they build some burrows in the upper few cm of soil; with a relatively short longevity and short generation time; they survive the drought only in the cocoon stage.

Aporrectodea turgida (Eisen, 1873) [=*Aporrectodea caliginosa* (Savigny, 1826)]

Ecological group: endogeic.

We collected specimens in poplar forest (rich in leaf litter or fallen leaves); in rocky areas within Cordón Esmeralda, in grassy lowlands, in pine forest with humid soils.

Origin: This species originates in Europe or adjacent parts of Asia.



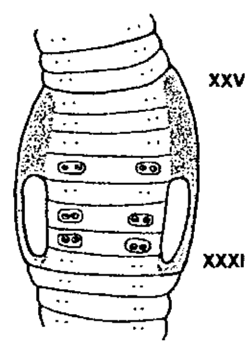
Aporrectodea turgida

Aporrectodea trapezoides (Dugès, 1828)

Ecological group: endogeic.

We found specimens mainly in highly modified habitats such as in grassy lowlands, in horse paths, and near pine forest.

Origin: This species originates in Europe or adjacent regions of Asia.



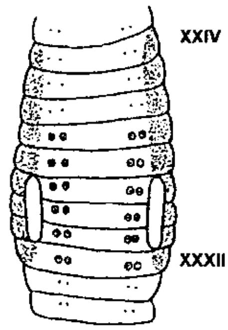
Aporrectodea trapezoides

Aporrectodea rosea (Savigny, 1826)

Ecological group: endogeic.

We collected worms only in pine forest.

Origin: This species originates in Europe or adjacent parts of Asia.



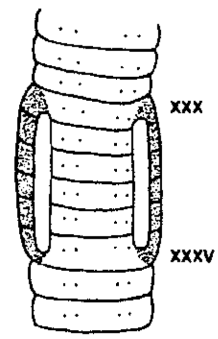
Aporrectodea rosea

Octolasion tyrtaeum (Savigny, 1826)

Ecological group: endogeic.

We found earthworms in a poplar forest (in association with *A. turgida*), in horse paths and near pine forest.

Origin: This species originates in Europe or adjacent parts of Asia.



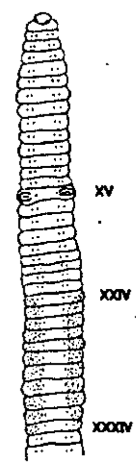
Octolasion tyrtaeum

Bimastos parvus (Eisen, 1874)

Ecological group: epigeic.

The specimens were collected at a streamside, in water-saturated soil, rich in organic matter.

Origin: This species is probably native to Europe or U.S.A. This is the first record for Buenos Aires province.



Bimastos parvus

Family Acanthodrilidae

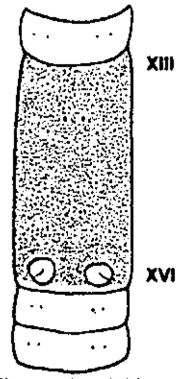
Representative members of this family are *Microscolex dubius* and *M. phosphoreus*, both possibly of South American origin. Currently they are widely distributed in southern temperate zones, North America and Europe, principally in agricultural and pastoral lands (Edwards & Bohlen, 1996).

Microscolex dubius (Fletcher, 1887)

Ecological group: endogeic species.

We found worms under cattle dung, tangled in mosses roots.

Origin: This species is probably native to Patagonia or subantarctic islands.



Microscolex dubius

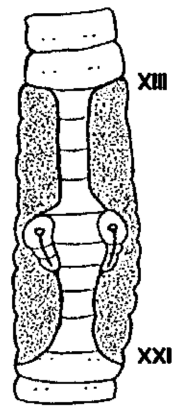
Family Ocnerodrilidae

This family has endemic representatives in the Americas from Argentine to southern U.S.A. and the Greater Antilles, and also in subsaharan Africa, with the possible inclusion of the Seychelles and Madagascar, in Egypt along the Nile and southern India (Ljungström, 1972).

Belladrilus jimi Righi, 1984

Ecological group: this species does not fit with any of the ecological groups described by Bouché, but we can consider it as an amphibious species.

The earthworms were collected in a stream, living submersed and tangled in roots of riparian vegetation.



Belladrilus jimi

Eukerria saltensis (Beddard, 1895)

Ecological group: as *B. jimi*, we can consider it as an amphibious species.

The specimens were found at a streamside, in saturated and swampy soils.

Origin: This species belongs to an endemic genus to South America, although being a wide spread species. This is the first record for Buenos Aires province.

Eukerria saltensis

Discussion

Unfortunately we did not found endemic earthworms within the Park. Most of them (60 %) are lumbricids world-wide distributed that are known as the principal group of peregrine species. Peregrine is a term used to describe some species of earthworms that are dispersed over a wide geographical range and have been transported by man or whose dispersal has been facilitated by man. They have special features such as potential self-breeding, polyploid inheritance, high tolerance to environmental variability, opportunism in food choice, capability to support chemical stress and ecological plasticity (Edwards & Bohlen, 1996).

In general, as with another invertebrates, native earthworms are vulnerable to habitat loss and disturbance. A replacement of endemics by exotics -in most cases, lumbricids- has been observed in many parts of the world. Generally this occurs concurrently with habitat destruction or fragmentation. It appears that large areas of intact habitat are somewhat more resistant to native species loss (Kalisz & Doston, 1989).

The absence of autochthonous species in the Park may be due to a historical non-occurrence of native species but we have no information to confirm that. The current earthworm composition might be reflecting the degree of habitat loss and disturbance in the ETPP.

9. CONSERVATION OUTPUT

Congresses and meetings

* Participation in the 'II Jornadas Interdisciplinarias del Sudoeste Bonaerense'. Oral presentation (SB) of the aim and perspectives of the present project.

* Participation in 'Jornadas de Tellus (20 aniversario)' (November 11^{th}-13^{th}). Meeting organised by Tellus (local NGO), open to general public and schools. The aim of this meeting was to inform about conservation activities and problems in the region. It included speeches of experts of the Universidad Nacional del Sur and permanent panel displays. We contributed with a panel display containing photographs and information about land snails and earthworms in Sierra de la Ventana, and with a display of empty shells, with information about its distribution and identification. Also, we presented a slideshow in a computer with photographs of land snails, earthworms, landscape and effects of horses over soil and grasslands, and impact of exotic woody plants in Ernesto Tornquist Provincial Park.

* We will present the results of the effects of environmetal variables and horses on land snail distribution and abundance, discussed in chapter 5, in the 'II Reunión Binacional de Ecología - XXI Reunión Argentina de Ecología- XI Reunión de la Sociedad de Ecología de Chile' (to be held in Mendoza, Argentina. October 31-November 5). Delhey V., S. Burela, N. Ghezzi, J. Pizá y N. Cazzaniga. 'Factores que afectan la distribución y abundancia de cuatro caracoles terrestres en el Parque Provincial Ernesto Tornquist (Sierra de la Ventana)'. Area: Conservation and management.

Publications and notes

* Burela S, NS Ghezzi, VK Delhey, J Pizá & NJ Cazzaniga, 2003. Caracoles y lombrices del Parque Provincial Ernesto Tornquist: Conservación de Invertebrados Terrestres. Actas de las II Jornadas Interdisciplinarias del Sudoeste Bonaerense: 169-182. EDIUNS (Universidad Nacional del Sur Press).

* Short note in ESLABÓN, periodical leaflet of TELLUS. 'Aspectos sobre la conservación de invertebrados'. (Aspects about invertebrate conservation). ESLABÓN, 9. June, 2002. Page 7.

* Short communication at Tentacle 11 (IUCN Mollusc Newsletter). 'Conservation project of land snails in the low mountain system of Ventania (Argentina).' Objectives of our project.

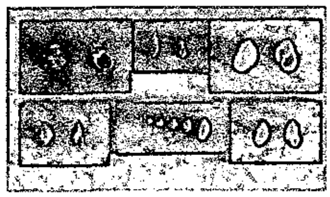
* Short note in ESLABÓN 13, a periodical leaflet of TELLUS: 'Caracol diminuto reaparece en Sierra de la Ventana tras cuarenta años de ausencia'

* Short note in ESLABÓN 13, a periodical leaflet of TELLUS: 'Lombrices en el Parque Provincial Ernesto Tornquist'.

Other contributions, through the Park and TELLUS

* Panel display for the Visitor Centre at the Park (attachment 6), with photographs, and information about distribution and conservation of autochtonous land snails.

* Exposition panel of shells of the autochtonous snails *Plagiodontes patagonicus, Discoleus aguirrei, Austroborus lutescens dorbignyi* and *Ventania avellanedae*, and the introduced garden snail *Helix aspersa,* with information about distribution and identification. Donated to the Visitor Centre at the Park.



* Guide for the land snail species in Sierra de la Ventana (attachment 7), offering information about species identification, biology, habitat and conservation relevance. There are two copies deposited at the library of the Park (for the primary use of researchers, tourist guides and Park rangers), and other two to the library of Tellus, which has an important collection about conservation, open to the community and used primarily by schoolteachers and students.

* Informal talks to the local tourist guides, and provision of photographs for the inclusion of land snails and earthworm in the conservation speeches and activities of tourist guides.

* General information of the project through the web site of TELLUS. www.tellus.org.ar

10. PUBLIC AWARENESS AND PRESS RELEASE

April 4th 2002. Local newspaper (La Nueva Provincia, page 1) published that our project won the *BP Conservation Programme* award. It briefly explained the purpose of the programme, the training workshops at the Royal Geographical Society, and the objectives of our project. It can be seen at http://www.lanuevaprovincia.com.ar/02/04/04/244037.sht

April 4th 2002. Local broadcasting (LU2 station, AM 840), same information as the newspaper.

April 4th 2002. One of us (JP) explained at four radio stations -FM Palihue, FM 102.3 (Bahía Blanca) and FM Río Colorado, FM 98.7 (Río Colorado)- the aim of our project and the importance of land snail conservation.

April 10th 2002. One of us (NSG) talked about the same topics at a local radio station (LU3, AM 1030).

July 2002. One of us (VKD) was interviewed (TV micro 'Valores Humanos', Channel 9 Bahía Blanca). Same topics as above.

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13. EXPENSES

Note: amounts are approximate, since there are changes in Pound sterling's currency.

Total: £ 2231

Pre Project expenses: £ 545

Maps £ 15; soil ph-moisture meter £ 80; soil thermometer £ 15; soil compaction tester £ 155; shipping chgs. £ 32; tax (*ca.* 50 % of merchandise total) £ 120; 6 books £ 98, others (shovel, wire, ropes, nylon bags, etc.) £ 30.

Field-expenses: £ 280

Living costs £ 60; first aid kit £ 25; travel costs £ 40; photography films £ 10; 128 MB disk for digital camera £ 70; rechargeable batteries (for digital camera and GPS) and charger £ 50; record tools £ 25.

Post-Project expenses: £ 1406

Ink cartridges £ 50; photography £ 15; cd's £ 7; fee (attendance to 'II Jornadas Interdisciplinarias del Sudoeste Bonaerense', x 4 persons) £ 30; postgraduate course on malacology, x 3 persons (fee, living costs) (Tucumán, Argentina, March 3-15 2003), £ 357; soil analysis £ 922; attendance fee to Congress on Malacology £ 25.

Future expenses:

Congress of Ecology (Mendoza, Argentina, October 31-November 5, 2004), travel and living costs.

Future publications and congresses.

List of documents attached:

1) **Article**: Burela S, NS Ghezzi, VK Delhey, J Pizá & NJ Cazzaniga, 2003. Caracoles y lombrices del Parque Provincial Ernesto Tornquist: Conservación de Invertebrados Terrestres. Actas de las II Jornadas Interdisciplinarias del Sudoeste Bonaerense: 169-182. EDIUNS (Universidad Nacional del Sur Press).
2) **Short communication** in ESLABÓN, periodical leaflet of TELLUS: 'Aspectos sobre la conservación de invertebrados'. ('Aspects about invertebrate conservation'). ESLABÓN 9, page 7, June 2002.
3) **Short communication** in TENTACLE 11, 2003 (IUCN Mollusc Newsletter). 'Conservation project of land snails in the low mountain system of Ventania (Argentina)'.
4) **Short communication** in ESLABÓN, periodical leaflet of TELLUS: 'Caracol diminuto reaparece en Sierra de la Ventana tras cuarenta años de ausencia'.
5) **Short communication** in ESLABÓN, periodical leaflet of TELLUS: 'Lombrices en el Parque Provincial Ernesto Tornquist'. ESLABÓN 13, page 8, 2004
6) **Panel display** (reduced version) for the Visitors' Centre at the 'Ernesto Tornquist' Provincial Park (photographs and information about distribution and conservation of autochthonous land snails)
7) **Guide for the land snail of Sierra de la Ventana** (information about species identification, biology, habitat and conservation relevance).
8) **Abstract for congress** submitted to 'II Reunión Binacional de Ecología - XXI Reunión Argentina de Ecología- XI Reunión de la Sociedad de Ecología de Chile', to be held in Mendoza, Argentina. October 31-November 5 2004: Delhey VK, S Burela, NS Ghezzi, J. Pizá y NJ Cazzaniga. 'Factores que afectan la distribución y abundancia de cuatro caracoles terrestres en el Parque Provincial 'Ernesto Tornquist' (Sierra de la Ventana)'. ('Factors affecting distribution and abundance of four land snails in the Ernesto Tornquist Provincial Park').
9) **Brochure 1 of the 'Ernesto Tornquist' Provincial Park** (activities for tourists and characteristics of the Park).
10) **Brochure 2 of the 'Ernesto Tornquist' Provincial Park** (information about the Education Conservation Programme of the Park).
11) **CD**: Photographs of the 'Ernesto Tornquist' Provincial Park and activities of our project.