Biodiversity and Conservation **11:** 1091–1104, 2002.

Terrestrial flatworm (Platyhelminthes: Tricladida: Terricola) diversity *versus* man-induced disturbance in an ombrophilous forest in southern Brazil

FERNANDO CARBAYO[1,*], ANA MARIA LEAL-ZANCHET[1] and EMERSON M. VIEIRA[2]

[1]*Instituto de Pesquisas de Planárias, Centro de Ciências da Saúde – Universidade do Vale do Rio dos Sinos (UNISINOS), Av. Unisinos 950, 93022-000 São Leopoldo-RS, Brazil;* [2]*Laboratório de Ecologia de Mamíferos, Centro de Ciências da Saúde – Universidade do Vale do Rio dos Sinos (UNISINOS), Av. Unisinos 950, 93022-000 São Leopoldo-RS, Brazil;* [*]*Author for correspondence (e-mail: fernando@cirrus.unisinos.br; fax: +55-51-5908122)*

Received 30 January 2001; accepted in revised form 25 June 2001

Key words: Bioindicators, Fragmentation, Geoplanidae, Platyhelminthes, Reforestation, Subtropical rainforest

Abstract. Terrestrial flatworms, or Terricola, are sensitive to environmental changes and therefore might be excellent indicators of the conservation status of natural habitats. The present study aimed to answer two main questions: (1) is terrestrial planarian diversity affected by human disturbances, and (2) is there any species or group of species that indicates such disturbance? The study site, National Forest of São Francisco de Paula, Brazil, was originally covered by a mixed ombrophilous forest, but successive reforestations and selective logging have modified the original landscape. We studied Terricola diversity in the four main habitats in the study area: mixed ombrophilous forest (NA), ombrophilous forest with selective *Araucaria angustifolia* logging (N), *A. angustifolia* reforestation (A), and reforestation of *Pinus elliottii* (P). According to an increasing degree of disturbance, the habitats might be ordered as follows: (NA)$<$(N)$<$(A)$<$(P). We conducted 24 surveys in each habitat over a period of 1 year. Our results indicate that: (1) Terricola diversity is inversely related to the degree of habitat disturbance; (2) there are species (*Geoplana franciscana*, *Geoplana* sp. 5, and possibly Geoplanidae 3 and *Notogynaphallia guaiana*) that prefer habitats located on the extreme right along the main axis of a detrended correspondence analysis ordination and therefore can be considered as indicators of well preserved, natural habitats. On the other hand there are species (*Xerapoa* sp. 1, *Choeradoplana iheringi*, *G. marginata* sensu Marcus and *Geoplana* sp. 2) preferring more disturbed habitats, which may form biological indicators of such disturbances.

Introduction

Terrestrial flatworms (Platyhelminthes: Tricladida: Terricola) feed on a wide range of invertebrates, like earthworms, terrestrial leeches, isopods, snails, insect larvae, and termites (Du Bois-Reymond Marcus 1951; Jones et al. 1995; Ogren 1995; Sluys 1999). Some Terricola are necrophagic and others can even prey on other flatworms, at least under laboratory conditions (Winsor 1977; W. Santos, personal communication). These animals are generally part of the soil cryptofauna (Winsor et al. 1998). They are stenohygric, depending strongly on the degree of humidity of its microhabitats for survival (Froehlich 1955c; Winsor et al. 1998; Sluys 1999). They indeed show preference for humid non-flooded habitats rather than wet ones (Froehlich and Froehlich 1972).

Terricola have a cosmopolitan distribution (Winsor et al. 1998) with about 808 known species (Ogren et al. 1997), most of them with restricted distribution (Sluys 1999). Nevertheless, the real number of species is probably much greater. In New Zealand, for instance, there are approximately 60 described species, but it is estimated that more than 100 occur (Johns 1998). Winsor (1997) estimates that only about 25% of the total number of species of Australian flatworms has been described, with 100 species currently known. In Brazil there are about 163 listed species, most of them occurring in areas of the southeastern Atlantic forest (Graff 1899; Du Bois-Reymond Marcus 1951; Marcus 1951; Froehlich E.M. 1955; Froehlich C.G. 1955a, b, 1956a, b, 1957, 1959). This biome comprises only about 15% of the Brazilian territory and the relatively small number of species in other vegetation types probably reflects the scant knowledge on flatworms in such areas. For instance, in an area of 1600 ha in southern Brazil, where the present study was conducted, 40 species were found of which only four had been previously described (Leal-Zanchet and Carbayo 2000).

The usefulness of Terricola as bioindicators of the state of the soil and the forest ecosystem has already been pointed out by Sluys (1998). This author suggested that from the comparison of the Terricola diversity in forests with different degrees of disturbance the conservation status of the ecosystem may be inferred. The same author proposed this taxon as a good indicator of areas of high general biodiversity (Sluys 1999).

In spite of recent efforts to intensify our knowledge on the biology of terrestrial flatworms, there is virtually no information about the potential effects of management and fragmentation of their natural habitat on the diversity of the worms. This information is even more scant for Neotropical areas. This study presents for the first time an analysis of the impact of forestry on a community of land planarians in a remnant of Neotropical forest. We addressed mainly two questions: (1) does man-induced habitat disturbance affect the diversity of Terricola, and (2) is there any species or group of species indicative of such disturbance?

Materials and methods

The National Forest of São Francisco de Paula (Figure 1) is a legally protected area established with management and conservation purposes. It is located in the northeast of the State of Rio Grande do Sul, RS, Southern Brazil (29°23′–29°27′ S, 50°23′–50°25′ O). The National Forest covers an area of ~1607 ha and is located at 930 m altitude, having an annual mean precipitation of 2468 mm year^{-1}. It was originally covered by a forest type named mixed ombrophilous forest (with araucaria pine, *A. angustifolia* (Bert.) Kuntze), but successive reforestations and selective logging have modified the original landscape.

There are four main habitats in this National Forest (IBDF 1989): mixed

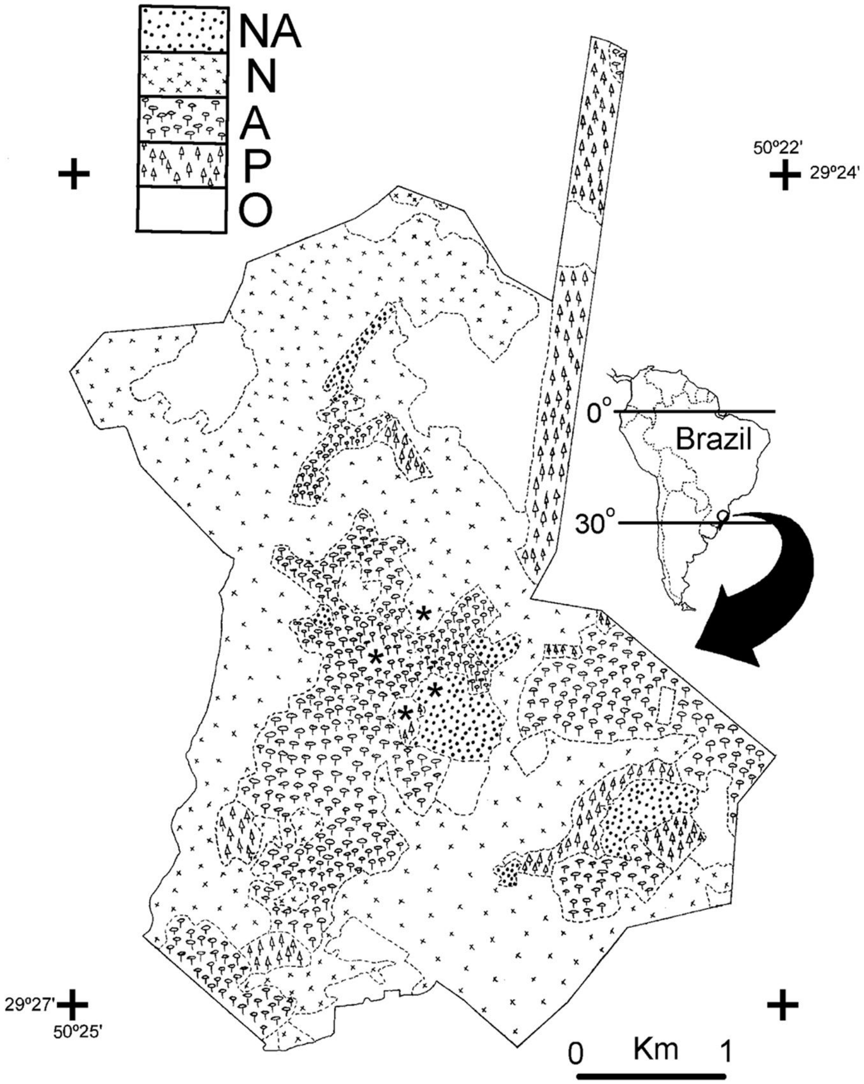

Figure 1. Location of the study area and distribution of the four main habitats of the National Forest of São Francisco de Paula, RS, Brazil. (A) – reforestation with araucaria pine; (N) – ombrophilous forest with selective araucaria pine logging; (NA) – mixed ombrophilous forest with araucaria pine (*A. angustifolia*); (O) – others (savanna, reforestation with *P. taeda*, *Eucaliptus* sp.); (P) – reforestation with *P. elliottii*. Modified from IBDF (1989). Asterisk marks indicate the location of the transects in each habitat.

ombrophilous forest (NA), ombrophilous forest with selective araucaria pine logging (N), araucaria pine reforestation (A), and reforestation with the exotic pine *P. elliottii* Engelm. (P). These habitats are now distributed as fragments of different sizes (Figure 1); according to an increasing degree of disturbance they can be ordered as follows: (NA)<(N)<(A)<(P).

Samplings were always conducted during the day and by an experienced collector (Carbayo). We sampled the four main habitats in the National Forest (Figure 1). For each habitat we randomly selected four transects of 30–50 m, approximately 10–30 m apart. We searched along each transect for flatworms during the same period of time (18 min). The sampling sequence of the transects was altered during each expedition in order to correct for possible decrease of the capture success at the end of the day due to collector fatigue. We searched for flatworms in the soil litter, under and inside fallen logs and branches, and under rocks. After inspection the branches, logs, and rocks were returned to their original position to avoid alteration of the microhabitats of the soil fauna (Ball and Reynoldson 1981; Winsor 1997). We performed 24 samplings (twice a month) between September 1998 and August 1999. For identification purposes we used techniques described by Leal-Zanchet and Carbayo (2001).

We estimated the probable number of species by using Chao's formula, $S_1^* = S_{obs} + (a^2/2b)$, because of its good performance with preponderance of relatively rare species (see Colwell and Coddington 1996), where S_{obs} is the observed richness in the sample, a the number of observed species represented in the sample by a single specimen, and b the number of observed species represented in the sample by two individuals. We calculated the Shannon–Wiener diversity index (H', see Krebs 1989) for each habitat and estimated the similarity among the habitats with the Morisita index (C_λ, see Krebs 1989). We also evaluated significant differences between diversity indices of pairs of habitats (t-test). As the t-test for Shannon–Wiener indices allows only two-sample comparisons, we used a level of significance (α) of 0.01 instead of 0.05 to keep a low probability (0.06) of commiting at least one type error (see Zar 1999). We applied the G-test (Zar 1999) to detect differences in the specific composition among transects of the same habitat and between habitats.

We performed a hierarchical grouping of the transects (Euclidean distance) and also a species and transect ordination (detrended correspondence analysis, DCA) using the software PC-ORD (McCune and Mefford 1997). To test relationships between the abundance of the species and the habitats we made correlation analyses between two variables: arcsine-transformed abundance of each species in each of the transects (Zar 1999), and scores of each transect on the first two axes obtained from the ordination.

Results

Abundances and distribution of species

We found 402 individuals, 379 of which could be identified, belonging to 28 species (Table 1). We collected approximately half of the animals for identification or other taxonomic studies. In the reforested area with *A. angustifolia* (A) the greatest number of individuals was recorded (47.2% of the observed total) and in the *P.*

elliottii reforestation (P) the lowest one (14.0%). *Geoplana ladislavii* Graff 1899 (32.4% of the total) and *Geoplana* sp. 1 (18.7%) were the most abundant species in the four habitats.

The selectively logged habitat (N) and the reforested area (A) were the richest

Table 1. Abundances of species of geoplanids (Platyhelminthes: Tricladida: Terricola) in four habitats in the National Forest of São Francisco de Paula, Rio Grande do Sul, Brazil.

Habitat type		(NA)				(P)				(N)				(A)					
Transect no.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
Species	Abbreviation																	Total	
G. ladislavii Graff L. (1899)	Gla	6	6	3	2	5	10	1	1	5	5	3	3	15	14	21	23	123	
Geoplana sp. 1[a]	Ge1	3	4	6	3	4	2	–	2	7	3	–	–	8	9	11	9	71	
G. franciscana Leal-Zanchet and Carbayo (2001)	Gef	–	6	7	–	–	–	–	–	3	5	2	3	6	2	1	2	37	
C. iheringi Graff 1899	Chi	1	–	4	2	3	1	3	–	1	2	–	–	1	2	–	2	22	
Geoplana sp. 2[a]	Ge2	4	–	–	–	–	2	5	1	–	2	2	–	–	1	2	1	20	
Geoplana sp. 3	Ge3	–	–	–	–	–	–	–	–	–	–	–	–	7	9	1	–	17	
G. marginata sensu Marcus (1951)	NoM	–	–	–	2	3	–	1	1	–	–	1	–	1	3	1	1	14	
G. josefi Carbayo and Leal-Zanchet (2001)	Gej	1	1	2	–	–	–	–	2	1	–	2	–	–	1	1	1	12	
Geoplanidae 1[b]	Gp1	–	–	–	–	–	–	–	–	–	–	2	1	–	2	2	1	8	C. araucariana
Geoplana sp. 4	Ge4	2	–	1	–	1	–	–	–	–	1	1	1	–	–	–	1	8	G. rubidolineata
Choeradoplana sp. 1[a]	Ch1	–	–	–	–	–	–	1	–	1	–	–	–	1	1	1	1	6	
Geoplanidae 2[b]	Gp2	1	–	2	–	–	–	–	–	2	–	–	–	1	–	–	–	6	
Notogynaphallia sp. 1[a]	No1	–	–	–	1	–	–	–	–	–	–	–	–	2	1	1	1	6	L. arturi
Geoplanidae 3	Gp3	1	–	–	–	–	–	–	–	1	1	1	1	–	–	–	–	5	
G. marginata sensu Graff L. (1899)	NoG	–	–	1	–	–	–	–	–	–	–	–	–	–	–	1	1	3	
N. guaiana Leal-Zanchet and Carbayo (2001)	Ngu	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	2	3	
Pasipha sp. 1[a]	Pa1	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	2	
Choeradoplana sp. 2[a]	Ch2	–	–	–	–	–	–	–	–	–	1	1	–	–	–	–	–	2	
Notogynaphallia sp. 2[a]	No2	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	2	L. ceciliae
Geoplanidae 4	Gp4	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	1	2	
Xerapoa sp. 1	Xe1	–	–	–	–	1	–	1	–	–	–	–	–	–	–	–	–	2	
Notogynaphallia sp. 3[a]	No3	–	1	–	–	–	–	–	–	1	–	–	–	–	–	–	–	2	L. pseudoceciliae
Geoplanidae 5[b]	Gp5	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	S. irritata
Pasipha sp. 2	Pa2	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	
Geoplana sp. 5	Ge5	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	1	
G. pavani? Marcus (1951)	Gpa	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	
Geoplana sp. 6	Ge6	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	1	
Geoplanidae 6	Gp6	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	1	
Not identified	–	2	2	–	1	2	–	1	–	5	2	1	3	–	2	1	1	23	
Total		24	20	27	11	20	15	13	8	29	22	16	14	43	47	44	49	402	

Habitat codes are as follows: (A) – reforestation with araucaria pine, *A. angustifolia*; (N) – subtropical rainforest with selective araucaria pine logging; (NA) – subtropical rainforest with araucaria pine; (P) – reforestation with *P. elliottii*. [a]Undescribed species. [b]Undescribed genus and species.

Table 2. Abundances, richness, diversity and number of geoplanid species in the National Forest of São Francisco de Paula, RS, Brazil. Habitat codes as in Table 1.

	(NA)	(N)	(A)	(P)
Number of individuals	77	70	179	53
Individual proportions (%)	20.3	18.8	47.2	14.0
Species richness	16	17	17	11
Number of unique species	3	2	3	3
Probable number of species (S^*_1)	25	21	18	15
S^*_1 increment (%)	56	23	6	36
Shannon–Wiener's diversity index (H')	3.272	3.467	2.856	2.849

sites, each with 17 species (Table 2). We registered 16 and 11 species in the mixed ombrophilous forest (NA) and the area reforested with *P. elliottii* (P), respectively. We found four groups of species that were each restricted to one of the habitats; each species was represented by one or two specimens, except *Geoplana* sp. 3, with 17 individuals. These species groups are: *Pasipha* sp. 1, *Pasipha* sp. 2 and Geoplanidae 5 in (NA); *Xerapoa* sp. 1, *Geoplana* sp. 6 and Geoplanidae 6 in (P); *Choeradoplana* sp. 2 and *Geoplana* sp. 5 in (N); *Geoplana* sp. 3, *G. pavani*? Marcus (1951) and Geoplanidae 4 in (A).

The estimated total number of species per habitat (S^*_1) indicated the highest increment (56%) of the potential number of species in habitat (NA), with the lowest increment (6%) occurring in (A). On the basis of an increasing probable number of species, the studied habitats can be ordered as follows: $S^*_{1(P)} < S^*_{1(A)} < S^*_{1(N)} < S^*_{1(NA)}$ (Table 2). We found the greatest diversity index $H' = 3.467$ in (N) and the lowest one, $H' = 2.849$, in (P) (Table 2). The highest similarity index among habitats was $C_\lambda = 1.039$, between (NA) and (N); the smallest one, $C_\lambda = 0.823$, between (N) and (P) (Table 3). The *t*-test indicated significant differences between diversity indices of the following two pairs of habitats: (N)–(A) and (N)–(P) ($P < 0.01$ for both pairs). The *G*-test indicated significant differences between the species composition of the four habitats ($G = 179.569$, $P = 0.000$), and between the transects of a same habitat for (NA) ($G = 67.896$, $P = 0.015$) and (P) ($G = 51.090$, $P = 0.010$). We did not find significant differences in species assemblages between the transects of the habitats (N) ($G = 60.755$, $P > 0.10$) and (A) ($G = 58.552$, $P > 0.14$).

Cluster analysis and transect ordination

The hierarchical analysis differentiated between three groups of transects and one

Table 3. Matrix of similarity coefficients, C_λ, among geoplanid communities of the four habitats of the National Forest of São Francisco de Paula, RS, Brazil. Habitat codes as in Table 1.

	(N)	(A)	(P)
(NA)	1.039	0.853	0.873
(N)		0.836	0.823
(A)			0.898

outlier, the latter formed by the transect of P7 (Figure 2). Each of the three groups is constituted mainly by transects of the same habitat. The first axis of the DCA (Figure 3A) (eigenvalue = 0.36) reflects differences in the specific composition among the habitats, grouping the transects of the disturbed habitat (P) at the left end of the axis. In the hierarchical analysis those transects formed two adjacent groups, I and II. All transects of (A) fall in a single group, II, in the central area of DCA 1. The transects of (N), a least disturbed habitat, are located on the right extreme of DCA 1, all of them in group III. Finally, the transects of the best preserved habitat (NA) mostly fall along the right extreme of that axis, belonging to group III. The second axis of the ordination, DCA 2 (eigenvalue = 0.22), shows a trend to segregate the transects of (A) from the remaining ones. The *G*-test confirmed the grouping of the transects accomplished in the hierarchical analysis.

According to the transect and group distribution in the ordination diagram, the first DCA axis most likely indicates a gradient of habitat disturbance (Figure 3A), with the transects of the most disturbed habitat (P) prevailing on the left side. The four transects of (A) are placed in the center of the first axis, indicating intermediate levels of disturbance. The transects of the least disturbed habitats, (N) and (NA), are located on the right extreme. For (NA), the relationship is not so clear because its transects are more dispersed along the axis.

In relation to the diversity indices, the first axis also represents a gradient, with the transects of the habitat with low values displaced on the left side. The transects of

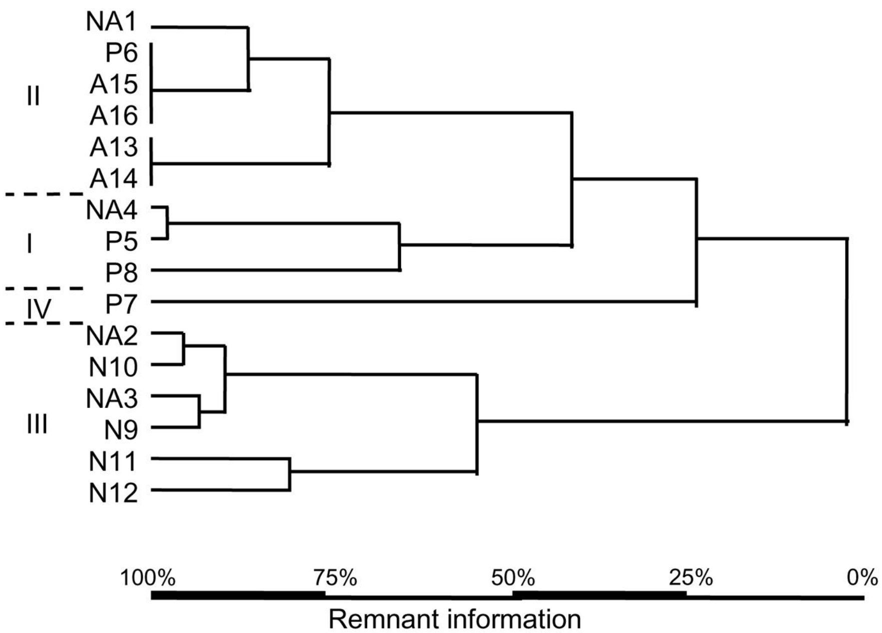

Figure 2. Results of the hierarchical cluster analysis (standardised Euclidean distance) of transects from the four main habitats in the National Forest of São Francisco de Paula, RS, Brazil. Roman characters identify three groups (I, II, III) and an outlier (IV), respectively.

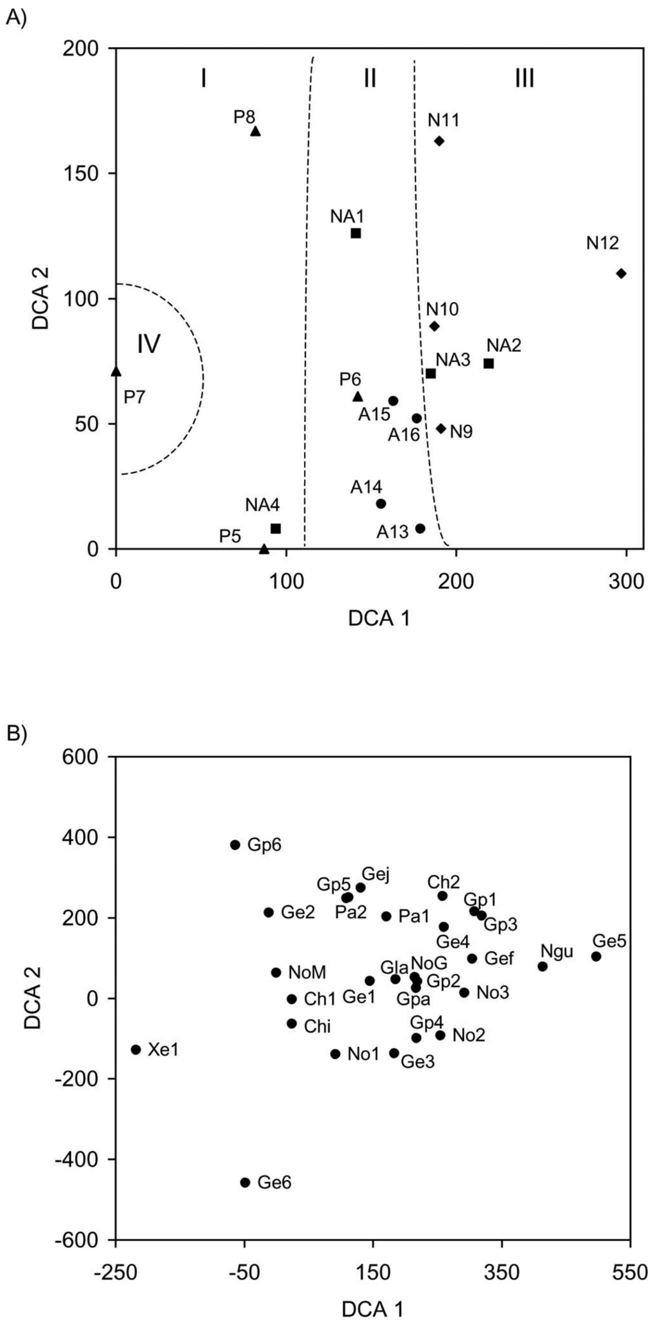

Figure 3. (A) Results of the DCA ordination analysis of the land flatworm communities of the transects in the four habitats of the National Forest of São Francisco de Paula, RS, Brazil. Broken lines separate three groups and an outlier identified by the cluster analysis (see Figure 2). (B) Results of the DCA ordination analysis for the 28 species occurring in the 16 sampled transects. Species codes as in Table 1.

the habitat with high diversity indices (N) are situated on the other extreme of the DCA 1. The transects of (A), with an intermediate value index, are located in the central region of the axis.

The graphic outlier, IV, represents a habitat with a particular species composition. This transect presents the greatest abundance of *Geoplana* sp. 2, and very low frequencies of the most common species in other habitats, *G. ladislavii* and *Geoplana* sp. 1, with one and zero specimens, respectively. Besides that, here we found one of the only two individuals of *Xerapoa* sp. 1.

Species ordination

Ubiquitous species (*G. ladislavii* and *Geoplana* sp. 1), occurring with high frequency in most of the transects, and unique species in (A) (Geoplanidae 4, *Geoplana* sp. 3, *G. pavani*?), are positioned in the central area of the ordination diagram (Figure 3B). Species restricted to one habitat tend to be located on the edge of the species' cloud in the ordination diagram (Figure 3B). Species that are either more abundant or unique in the habitats located to the left of the axis appear to prefer more disturbed habitats. Similarly, the most frequent or unique species in the habitats located on the opposite side on DCA 1 show preferences for non-disturbed habitats. This is also detected in the correlation coefficients (Table 4): *G. franciscana* Leal-Zanchet and Carbayo 2001 and *Geoplana* sp. 5, with a significant positive correlation coefficient, appear to be more sensitive to alterations of the original habitat. These species and possibly Geoplanidae 3 and *Notogynaphallia guaiana* Leal-Zanchet and Carbayo 2001 (both showing marginally significant correlations, $P = 0.054$ and $P = 0.057$, respectively) are more abundant or exclusive of the habitats placed at the right end of DCA 1, i.e., (N) and (NA). Thus this group might indicate less disturbed areas. The other group is formed by species significantly and negatively correlated with DCA 1. These species (*Xerapoa* sp. 1, *C. iheringi*, *G. marginata* sensu Marcus and *Geoplana* sp. 2) are more frequent in those habitats displaced to the left on DCA 1, that is, they apparently show preference for homogeneous reforested areas, the most disturbed habitats.

Discussion

Terricola diversity and habitat characteristics

Several factors such as pH, depth, temperature, texture and humidity of the soil, prey abundance, and presence of refuges in the soil potentially influence the distribution of terrestrial flatworms (Springett 1976; Alford et al. 1998; Boag et al. 1998a, b; Sluys 1998; Winsor 1998). Additionally, land flatworms may perform vertical migrations (Boag et al. 1998a; Jones et al. 1998), and soil compaction probably might hinder this behaviour.

Our results suggest that the occurrence of Terricola depends on the kind of environmental alteration suffered by their habitat. In the habitat reforested with

Table 4. Pearson's correlation coefficient, *r*, of geoplanid species with the first two DCA axes.

Species	Abbreviation	DCA 1	DCA 2
C. iheringi Graff L. (1899)	Chi	−0.638[a]	0.282
Choeradoplana sp. 1	Ch1	−0.350	0.340
Choeradoplana sp. 2	Ch2	0.180	−0.511[b]
G. franciscana Leal-Zanchet and Carbayo (2001)	Gef	0.805[a]	−0.106
G. josefi Carbayo and Leal-Zanchet (2001)	Gej	0.111	−0.491[a]
G. ladislavii Graff L. (1899)	Gla	0.292	0.420
G. pavani? Marcus (1951)	Gpa	0.071	0.153
Geoplana sp. 1	Ge1	−0.003	0.622[b]
Geoplana sp. 2	Ge2	−0.590[b]	−0.531[b]
Geoplana sp. 3	Ge3	0.086	0.602[b]
Geoplana sp. 4	Ge4	0.334	−0.572[b]
Geoplana sp. 5	Ge5	0.518[b]	−0.259
Geoplana sp. 6	Ge6	−0.251	0.142
Geoplanidae 1	Gp1	0.439	−0.282
Geoplanidae 2	Gp2	0.179	0.033
Geoplanidae 3	Gp3	0.490[c]	−0.619[b]
Geoplanidae 4	Gp4	0.0[d]	0.0[d]
Geoplanidae 5	Gp5	−0.078	−0.291
Geoplanidae 6	Gp6	−0.210	−0.312
N. guaiana Leal-Zanchet and Carbayo (2001)	Ngu	0.485[c]	−0.134
G. marginata sensu Graff L. (1899)	NoG	0.153	0.129
G. marginata sensu Marcus (1951)	NoM	−0.636[b]	0.157
Notogynaphallia sp. 1	No1	−0.095	0.705[a]
Notogynaphallia sp. 2	No2	0.142	0.095
Notogynaphallia sp. 3	No3	0.314	0.089
Pasipha sp. 1	Pa1	0.033	−0.260
Pasipha sp. 2	Pa2	−0.078	−0.291
Xerapoa sp. 1	Xe1	−0.707[a]	−0.042

[a]Significant correlation ($P < 0.01$); [b]significant correlation ($P < 0.05$); [c]marginally significant correlation ($P \leq 0.057$); [d]not computed.

exotic pine (P), there are probably the worst conditions for land planarians, due to its low complexity, low availability of refuges (scarcity of fallen logs and leaf litter), high incidence of solar light on the soil surface, and the relatively high soil compaction (F. Carbayo, personal observation). In fact, this is the area with the lowest diversity among all habitats. This diversity might even be overestimated because of the reduced size of (P) (about 2 ha). This small size may have artificially increased Terricola diversity because of the dispersal abilities of terrestrial flatworms (see Mather and Christensen 1998) and their capacity to survive long periods without feeding (W. Santos, personal communication). Most likely, these characteristics facilitate the invasion of relatively inadequate habitats. However, some species, like *Geoplana* sp. 1, apparently are able to complete their life cycle in (P), as indicated by the occurrence of all life cycle stages (cocoons, youngs, adults and matures) in this area.

In contrast to habitat (P), the area reforested with araucaria pine (A) contains a great number of apparently favourable microhabitats. The soil is relatively less compact and has a great number of fallen logs (F. Carbayo, personal observation).

This may explain the fact that the transects of this habitat show high species richness despite their low habitat heterogeneity, as all of them are grouped close to each other in the DCA (Figure 3A). This low heterogeneity is probably a consequence of the monospecific reforestation performed in this area.

As in the habitat reforested with araucaria pine (A), the other two habitats with ombrophilous forest, (N) and (NA), also have apparently favourable microhabitats for Terricola (F. Carbayo, personal observation). These three habitat types have a similar species richness but the transects of (N) and (NA) are more scattered in the ordination diagram. This scattering may reflect a higher habitat heterogeneity and, consequently, a higher potential diversity. The ombrophilous forest without *Araucaria* logging (NA), the best preserved habitat, has the most dispersed transects, placed among the three groups of the ordination diagram. This positive relationship between graphical dispersion of transects (reflecting microhabitat heterogeneity) and diversity was confirmed by the estimated species richness (S_1^*), with (NA) showing the highest value, followed by the habitat of ombrophilous forest with *Araucaria* logging (N).

Species composition and habitat disturbance

At present there is little information available on the physiological limitations concerning each land planarian species. Nevertheless, those species that indicate disturbed habitats probably are more easily adaptable to modified environmental conditions. There is evidence that this is the case for the species we studied. Next to the study area two specimens of *G. marginata* sensu Marcus were found copulating in a very disturbed isolated patch of primary forest of about 0.5 ha. Specimens of *C. iheringi* and *G. ladislavii* also occur in other man-disturbed areas, close to human habitations and in man-made fire-breakers in the same study area. *Geoplana ladislavii* also occurs in distinctly urban habitats, such as small gardens in cities and deposits of dumps and gardening remains (F. Carbayo, personal observation). In our study this species did not show significant correlation with DCA 1, probably because it is a generalistic species.

The variation in species composition among the study sites appears not to be limited to flatworms. The abundance of potential prey items also varied. We observed that, for instance, diplopodes were more numerous in (NA), whereas the exotic snail *Deroceras* sp. is more frequent in habitat (A). Although there are no published studies on the diet of the Terricola occurring in the study area, during the field work we observed species of Terricola feeding on opiliones, isopodes, cockroaches, leeches, and earthworms. It is also known that several species have such restricted alimentary requirements that their maintenance in the laboratory is very difficult (W. Santos, personal communication; F. Carbayo, personal observation). This suggests that the geographical distribution of at least some land planarian species is restricted by prey availability.

Sluys (1999) identified the Atlantic forest as one of the areas with highest diversity of Terricola on a global scale. In Brazil, this biome is protected by national and international laws (Conselho Brasileiro da Reserva da Biosfera 1999). The ombrophilous forest is considered to belong to the Atlantic forest, but in spite of the conservation efforts in 1990, only 10.5% of its original covering remains (Fundação SOS Mata Atlântica & INPE 1993). In the present study we performed an analysis of the variation of land planarian species composition in a subtropical rainforest, which has undergone different degrees of disturbance. Our results show that the diversity of the group is affected by the type of forest management.

The present study also demonstrates the ecological importance of the study site, inferred by the species richness of land flatworms. Besides that, some species can be valuable as indicators of the degree of disturbance suffered by their habitats. The species that prefer habitats located on the extreme right along the main axis of the DCA ordination (*G. franciscana*, *Geoplana* sp. 5, and possibly Geoplanidae 3 and *N. guaiana*) may be considered as indicators of well preserved habitats. On the other hand, there are species (*C. iheringi*, *Geoplana* sp. 2, *G. marginata* sensu Marcus and *Xerapoa* sp. 1) preferring more disturbed habitats that might be used as indicators of such disturbance. Terricolan species, with the restrictions imposed by their natural distribution, might serve as reliable indicators of undisturbed habitats and their biotic conditions and also of areas with the largest general biodiversity in the subtropical forest.

The natural history of terrestrial flatworms is of great interest for paleogeographical (Froehlich 1967; Sluys 1994, 1995) and evolutionary studies (Sluys 1998). As we have shown here, this taxon can be used as an indicator of man-induced disturbance. Besides the biological and intrinsic value of Terricola, information on their distribution and habitat preferences may provide valuable guidelines for faunal conservation programs and landscape management.

Acknowledgements

We are grateful to D. Guadagnin, M.Sc., for the valuable orientation on the field techniques and statistical consultantship. We also thank W. Santos, for the information on culture techniques of Terricola, and J. Rodrigues and L.A. Guterres for their help in the preparation of histological sections. An early version of this manuscript was kindly revised by Dr R. Sluys. This study was partially supported by the Fundação de Amparo à Pesquisa do Rio Grande do Sul (FAPERGS).

References

Alford D.V., Boag B., Johns P.M. and Yeates C.W. 1998. Report on the OECD workshop on terrestrial flatworms. Pedobiologia 42: 385–388.

Ball I.R. and Reynoldson T.B. 1981. British Planarians. Cambridge University Press, Cambridge, UK.

Boag B., Jones H.D., Evans K.A., Neilson R., Yeates G.W. and Johns P.M. 1998a. The application of GIS techniques to estimate the establishment and potential spread of *Artiophostia triangulata* in Scotland. Pedobiologia 42: 504–510.

Boag B., Yeates G.W. and Johns P.M. 1998b. Limitations to the distribution and spread of terrestrial flatworms with special reference to the New Zealand flatworm (*Artioposthia triangulata*). Pedobiologia 42: 495–503.

Colwell R.K. and Coddington J.A. 1996. Estimating terrestrial biodiversity through extrapolation. In: Hawksworth D.L. (ed.), Biodiversity. Measurement and Estimation. Chapman & Hall, London, pp. 101–118.

Conselho Brasileiro da Reserva da Biosfera (1999) Mata Atlântica. Ciência, conservação e políticas. Workshop científico sobre a mata atlântica. Cad. 15. Conselho Nacional da Reserva da Biosfera de Mata Atlântica.

Du Bois-Reymond Marcus E. 1951. On South American geoplanids. Boletim da Faculdade de Filosofia, Ciências e Letras da Universidade de São Paulo 16: 217–255.

Froehlich C.G. 1955a. Notas sôbre geoplanas brasileiras. Papéis Avulsos do Departamento de Zoologia 12: 189–198.

Froehlich C.G. 1955b. Sôbre morfologia e taxonomia das Geoplanidae. Boletim da Faculdade de Filosofia, Ciências e Letras da Universidade de São Paulo 19: 195–279.

Froehlich C.G. 1955c. On the biology of land planarians. Boletim da Faculdade de Filosofia, Ciências e Letras da Universidade de São Paulo 20: 263–271.

Froehlich C.G. 1956a. Planárias terrestres do Paraná. Dusenia 7: 173–196.

Froehlich C.G. 1956b. Tricladida Terricola das regiões de Teresópolis e Ubatuba. Papéis Avulsos do Departamento de Zoologia 12: 313–344.

Froehlich C.G. 1957. On a collection of Brazilian land planarians. Boletim da Faculdade de Filosofia, Ciências e Letras da Universidade de São Paulo 21: 93–121.

Froehlich C.G. 1959. On geoplanids from Brazil. Boletim da Faculdade de Filosofia, Ciências e Letras da Universidade de São Paulo 22: 201–265.

Froehlich C.G. 1967. A contribution to the zoogeography of neotropical land planarians. Acta Zoológica Lilloana 23: 153–162.

Froehlich E.M. 1955. Sôbre espécies brasileiras do gênero *Geoplana*. Boletim da Faculdade de Filosofia, Ciências e Letras da Universidade de São Paulo 19: 289–369.

Froehlich E.M. and Froehlich C.G. 1972. Land planarians from the Amazonian Region. Papéis Avulsos do Departamento de Zoologia 26: 29–45.

Fundação SOS Mata Atlântica & INPE 1993. Evolução dos remanescentes florestais e ecossistemas associados do domínio da Mata Atlântica no período 1985–1990 – relatório. Fundação SOS Mata Atlântica, São Paulo.

Graff L. von 1899. Monographie der Turbellarien: II. Tricladida Terricola. Engelmann, Leipzig.

IBDF 1989. Floresta Nacional de São Francisco de Paula-RS. Mapa de classes de idades. Scale 1:10000.

Johns P.M. 1998. The New Zealand terrestrial flatworms: a 1997–98 perspective. Pedobiologia 42: 464–468.

Jones H.D., Cumming M.S. and Kennaugh J.H. 1995. The anatomy of *Microplana termitophaga* from Zimbawe and Kenya: a confirmation of the subfamily and genus. Hydrobiologia 305: 121–126.

Jones H.D., Green J. and Palin D.W. 1998. Monthly abundance, size and maturity in a population of the 'Australian flatworm', *Australoplana sanguinea alba*. Pedobiologia 42: 511–519.

Krebs C.J. 1989. Ecological Methodology. Harper & Row, New York.

Leal-Zanchet A.M. and Carbayo F. 2000. Fauna de planárias terrestres da Floresta Nacional de São Francisco de Paula, RS: uma análise preliminar. Acta Biologica Leopoldensia 22: 19–25.

Leal-Zanchet A.M. and Carbayo F. 2001. Two new species of Geoplanidae (Platyhelminthes, Tricladida, Terricola) from South Brazil. Journal of Zoology 253: 433–446.

Marcus E. 1951. Turbellaria brasileiros (9). Boletim da Faculdade de Filosofia, Ciências e Letras da Universidade de São Paulo 16: 5–215.

Mather J.G. and Christensen O.M. 1998. Behavioural aspects of the 'New Zealand flatworm', *Artioposthia triangulata*, in relation to species spread. Pedobiologia 42: 520–531.

McCune B. and Mefford M.J. 1997. PC-ORD: Multivariate Analysis of Ecological Data, Version 3.18. MjM Software Design, Gleneden Beach, Oregon.

Ogren R.E. 1995. Predation behaviour of land planarians. Hydrobiologia 305: 105–111.

Ogren R.E., Kawakatsu M. and Froehlich E.M. 1997. Additions and corrections of the previous land planarian indices of the world (Turbellaria, Seriata, Tricladida, Terricola). Addendum IV. Geographic

locus index: Bipaliidae, Rhynchodemidae (Rhynchodeminae; Microplaninae); Geoplanidae (Geoplaninae; Caenoplaninae; Pelmatoplaninae). Bulletin of the Fuji Women's College 35: 63–103.
Sluys R. 1994. Explanations for biogeographic tracks across the Pacific Ocean: a challenge for paleogeography and historical biogeography. Progress in Physical Geography 18: 42–58.
Sluys R. 1995. Platyhelminths as paleogeographical indicators. Hydrobiologia 305: 49–53.
Sluys R. 1998. Land planarians (Platyhelminthes, Tricladida, Terricola) in biodiversity and conservation studies. Pedobiologia 42: 490–494.
Sluys R. 1999. Global diversity of land planarians (Platyhelminthes, Tricladida, Terricola): a new indicator-taxon in biodiversity and conservation studies. Biodiversity and Conservation 8: 1663–1681.
Springett J.A. 1976. The effects of prescribed burning on the soil fauna and on litter decomposition in Western Australian forests. Australian Journal of Ecology 1: 72–82.
Winsor L. 1977. Terrestrial planarians and nemerteans of the Otway region. Proceedings of the Royal Society of Victorian Museum 89: 137–146.
Winsor L. 1997. The biodiversity of terrestrial flatworms (Tricladida: Terricola) in Queensland: a preliminary report. Memoirs of the Museum Victoria 56: 575–579.
Winsor L. 1998. The Australian terrestrial flatworm fauna (Tricladida: Terricola). Pedobiologia 42: 457–463.
Winsor L., Johns P.M. and Yeates G.W. 1998. Introduction, and ecological and systematic background, to the Terricola (Tricladida). Pedobiologia 42: 389–404.
Zar J.H. 1999. Biostatistical Analysis. Prentice Hall, Englewood Cliffs, New Jersey.