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Effects of direct human disturbance on the endemic Iberian frog *Rana iberica* at individual and population levels

Iñaki Rodríguez-Prieto [a], Esteban Fernández-Juricic [b,*]

[a] *Departamento de Ecología Evolutiva, Museo Nacional de Ciencias Naturales, CSIC, José Gutiérrez Abascal 2, 28006 Madrid, Spain*
[b] *Department of Biological Sciences, California State University – Long Beach, Peterson Hall 1-109,*
1250 Bellflower Building, Long Beach, CA 90840, USA

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Abstract

There is widespread concern about the global decline of amphibians, but little is known about whether and how direct human disturbance might affect populations. The goal of this study was to assess the effects of recreational activities on Iberian frogs *Rana iberica*, an endemic and vulnerable species of the Iberian Peninsula, through observation and manipulative approaches. At the population level, we found that frog abundance decreased with the proximity to recreational areas. At the individual level, the behavioral responses of frogs to repeated disturbance events increased the time to resume pre-disturbance activities, but did not affect significantly flight initiation distances. We simulated different levels of human visitation to the stream banks, and found 80% and 100% decrease in stream bank use with a fivefold and a 12-fold increase in direct disturbance rate, respectively. Recreational activities are negatively affecting Iberian frogs through a loss in the spatial and temporal availability of resources. To reduce the level of local disturbance to this species, we recommend setting up buffer areas >2.5 m from the streams or reducing visitor rates to fewer than 5 visits per hour (either groups or individuals). The role of direct human disturbance should be considered further as a potential factor affecting local amphibian declines.

Keywords: Buffer areas; Direct human disturbance; Population decline; Risk-disturbance hypothesis; Tourism

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1. Introduction

There is widespread concern about a global decline in amphibian populations (Blaustein and Wake, 1990; Wake, 1998; Houlahan et al., 2000). Habitat alteration, overexploitaition, exotic species introductions, emerging infectious diseases, UV-B radiation, chemical pollutants, and climate change are all proposed causes for amphibian declines (Collins and Storfer, 2003). However, the decline seems to be affected by a combination of factors that may trigger synergistic effects on a species-specific and region-specific basis (Kiesecker et al., 2001; Blaustein and Kiesecker, 2002; Collins and Storfer, 2003). Regardless of the specific factors involved, some authors have proposed amphibians as good indicators of environmental stress (Blaustein, 1994; Blaustein and Wake, 1995).

The increase in tourism and outdoor recreational activities has recently been considered as a new major threat to biodiversity worldwide, as the rate of human visitation to the world's biodiversity hotspots is expected to double by 2020 (Christ et al., 2003). The effects of recreational activities have been studied in reptiles (e.g., Hecnar and M'Closkey, 1998; Lacy and Martins, 2003), birds (e.g., Cornelius et al., 2001; Fernández-Juricic, 2002, Rees et al., 2005), and mammals (e.g., De la Torre et al., 2000; Papouchis et al., 2001) in both

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[*] Corresponding author.
E-mail address: efernand@csulb.edu (E. Fernández-Juricic).

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terrestrial and aquatic habitats. However, relatively little attention has been devoted to amphibians, a group in which despite a growing literature on *indirect* human disturbance effects, there is a lack of information on *direct* human disturbance effects (Maxell and Hokit, 1999). Given that aquatic environments attract many recreationists; it is likely that amphibian populations inhabiting highly visited areas may be affected. If so, tourism should be considered as an important factor when assessing local declines in amphibian populations.

We hypothesize that the mechanism regulating human-frog interactions will be the relationship between the frequency of resource use by frogs and the frequency of human visitation (resource-use disturbance trade-off hypothesis, Fernández-Juricic, 2000, 2002; Fernández-Juricic et al., 2003). This hypothesis can be considered a special case of the risk-disturbance hypothesis, which holds that animals seek a balance between avoiding disturbance and pursuing activities that may increase fitness, such as foraging, mating, and parental care (Frid and Dill, 2002). This effect of increased disturbance could potentially reduce the suitability and carrying capacity of disturbed areas, with consequent reductions in frog density (Fernández-Juricic, 2000).

The goal of this study was to assess the effects of recreational activities on Iberian frogs *Rana iberica*, an endemic species in decline and listed as vulnerable in the Spanish Red Data Book (García-París et al., 1989; Ayllón and Domínguez, 2001; Esteban and Martínez-Solano, 2002). We followed a combination of approaches. At the population level, we assessed the effects of environmental factors and the proximity to roads and recreational areas on the abundance of Iberian frogs in areas with a long and a short history of human visitation. At the individual level, we first studied the behavioral responses of frogs to simulated approaches to determine the effects of repeated and localized disturbance events on flight initiation distance and time to resume pre-disturbance activities. We also estimated minimum approaching distances (areas that should not be encroached to reduce disturbance). Second, we simulated different levels of human visitation within minimum approaching areas to assess the degree to which habitat use would be reduced and to predict management scenarios that would decrease disturbance. Our intention was to give recommendations as to how to promote coexistence between Iberian frogs and recreationists, as outdoor recreation is an important resource for local communities.

2. Methods

2.1. Study site

The study was conducted in the Guadarrama Mountains (40°45′N, 4°05′W), Central Spain, 60 km northwest of Madrid city. Because of its proximity to Madrid, the Guadarrama Mountains attract about 2.7 million visitors per year (Gómez-Limón et al., 1994). The Guadarrama Mountains are dominated mainly by homogeneous *Pinus sylvestris* forests (1200–1900 m elevation). Below that level, forests of *Quercus pyrenaica* and *Quercus ilex ballota* occur across an increasingly urbanized landscape. Alpine grasslands and shrubs (mainly *Cytisus oromediterraneus* and *Juniperus communis alpina*) occur above 1900 m (Sánchez et al., 2001). We chose two study areas dominated by *Pinus sylvestris* forests: Valsaín (40°51′N, 4°01′W) and Peguerinos (40°40′N, 4°12′W). Visitors come to these areas mainly to walk. Mountain-biking, horse-riding and off-road driving occur only rarely. Valsaín has been frequented by tourists for more than 40 years (Folgado, 2002); whilst Peguerinos received fewer visitors in the same period of time because it is farther away and more isolated from Madrid; however, tourist numbers are now increasing.

Sampling was conducted between mid-August and early-October 2002, on sunny days without wind. This sampling period fell in-between the mid-summer activity pause that occurs only during the hottest years and the winter inactivity period experienced by some mountain populations of Iberian frog (García-París, 1985). Maximum daily temperature and relative humidity records for each sampling day at Valsaín and Peguerinos were obtained from weather stations at Puerto de Navacerrada and San Rafael, respectively.

2.2. Study species

The Iberian frog is an endemic species of the Iberian Peninsula, with the Guadarrama Mountains being the easternmost limit of its range in central Spain (Esteban and Martínez-Solano, 2002). In this area, it inhabits mountain streams, with tadpoles developing in the pools and adults sunbathing and feeding on the stream banks (García-París, 1985). When the frogs are disturbed, they jump into the streams (García-París, 1985). This species shows both diurnal and nocturnal activity, the proportions of which vary between populations (García-París, 1985). In both of our study areas, the frog was predominantly diurnal (Rodríguez-Prieto, unpublished data).

2.3. Frogs population abundance

We surveyed the Iberian frog in 35 stream transects in Peguerinos and Valsaín (for a similar methodological approach see Heyer et al., 1994; Parris et al., 1999; Kam and Chen, 2000; Parris, 2001). Stream transects have been shown to yield more accurate results in riparian habitats compared to other amphibian surveying methods, such as pitfall traps (Parris et al., 1999). We used 180 m long transects to enable statistical comparisons to be made due to low-population densities (Ayllón and Domínguez, 2001). Frogs were easily detected along the stream banks due to the lack of tall herbaceous vegetation. In a preliminary survey, we found out that all frogs were detected at less than 0.40 m from the stream bank; but, we conservatively established transect widths of 2 m from each stream bank. We simultaneously walked at a constant speed along both stream banks of the stream transect, recording individuals seen within the transect.

We recorded the distance from the center of each transect to the nearest road and to the nearest visitor recreational area (e.g., camp site, picnic site, or village), as these were considered measures of human disturbance (for a similar approach in birds, see Ontiveros and Pleguezuelos, 2003; Sarà and Di Vittorio, 2003). We also recorded environmental factors, which might affect frog abundance, at 30 m intervals along each transect (5 per transect). We visually estimated tree cover (within 5 m radius circular plots), and measured stream width (in m). Cover measurements were estimated visually following Prodon and Lebreton (1981). We measured slope (low <8%, medium 8–16%, and high >16%), and elevation (m.a.s.l.), using 1:50000 topographic maps available at the Instituto Geográfico Nacional.

2.4. Effects of repeated disturbance on individual responses

This study was conducted only in Peguerinos, where Iberian frog abundance was relatively high. We recorded the flight initiation distance (FID) of individual frogs by approaching the animals with a steady pace (1 step/s). FID was defined as the distance (measured with a meter tape) between the observer and the frog when the latter jumped into the water in response to our approach. The location of disturbed frogs was marked.

We also recorded the time to resume pre-disturbance activities at the disturbed spot. We assessed two methods for recording this variable: (I) staying in the area until frogs returned to the stream bank after being disturbed and (II) leaving the area and returning after specific periods of time. Method I proved unsuccessful, and so we used Method II and recorded the presence/absence of frogs in the disturbed stream bank at four time intervals (0–5 min, 5–10 min, 10–15 min, and >15 min. after disturbance). After disturbing frogs, marking the fleeing point, and leaving the area, we returned 5 min later, and searched both stream banks thoroughly within a 4 m radius of the location of a disturbed frog for 25 s. If the frog was not on the stream bank, we left the area and repeated the process at 5 min intervals until the frog was either present on the stream bank, or more than 15 min had passed.

Our observation unit was the area by the stream where a frog was disturbed, and not the individual frog. In order to assess the effects of repeated disturbances on FID and on the time to resume pre-disturbance activities, we sampled areas where frogs were disturbed once ($n = 25$), twice ($n = 25$), and three consecutive times ($n = 21$). We used different individuals to measure responses to different numbers of disturbance events. Sample sizes varied among categories, because it was difficult to obtain samples from spots with frogs disturbed three times, as some frogs did not return to the stream banks even 20 min after being disturbed. Disturbance involved approaching a frog, followed by the frog jumping into the water. When frogs were disturbed once, FID and time to resume pre-disturbance activities were recorded, following the method described above. Response variables were also measured after two and three disturbance events, which were separated by 20 min intervals. If, when trying to carry out a second or third disturbance event, the frog was not present where it had been first disturbed, we discarded the observation. We also assessed the relationship between FID and time to resume pre-disturbance activities to determine if both response variables could be associated.

Toe-clipping was not used to mark individuals because of its deleterious effects on frog behavior and survival. Nevertheless, we have a high degree of certainty that the frogs that emerged from the water after disturbance were the ones we initially disturbed, because: (a) frogs are relatively solitary, space out along the stream, and show high site fidelity (Rodríguez-Prieto, unpublished data), (b) we only approached solitary individuals, avoiding situations where two or more were frogs separated by less than 8 m, and (c) we visually estimated the size (small, medium and large) and colour (light and dark) of individual frogs.

After recording frog FID and time to resume pre-disturbance activities, we measured several independent variables: water depth (measured with a meter stick at 1/4, 1/2 and 3/4 of the distance across the stream), water velocity (slow <25 cm/s, medium 25–50 cm/s, and fast >50 cm/s, measured with a floating object), and stream width, as potential confounding factors. We recorded stream bank substrate composition around the disturbance point: silt, sand, stone, and herb cover (%), and mean herb height in a rectangle 1 m long and 0.5 m wide with the long axis parallel to the stream and centered on the disturbance point. We also recorded the percentage of tree cover, but in a 5 m radius circular plot, centered on the fleeing point. Cover and height variables were visually estimated following Prodon and Lebreton (1981), and were recorded because of their known influence on disturbance behavior (e.g., Martín and López, 1995).

2.5. Minimum approaching distance

The minimum approaching distance was determined using FID and was derived by plotting the cumulative percentage of individuals fleeing against FID (Anthony et al., 1995). We reported the FID point at which 95% of the individuals flushed (McGarigal et al., 1991). We then measured the distance from water at which undisturbed frogs were located, and we used this distance as an estimate of the portion of the stream banks regularly used by frogs. We also considered the distance from water at which undisturbed frogs were usually located to estimate minimum approaching distance.

2.6. Stream bank use in relation to manipulations of visitor rate

This study was conducted at both Peregrinos and Valsaín. The intervals between visitors passing by a resource patch is expected to affect the rate at which animals make use of that resource patch (Fernández-Juricic et al., 2003). We then simulated three different visitor rates along 180 m long stream transects: low (1 person/h/stream bank, $n = 25$), medium (5 people/h/stream bank, $n = 25$), and high (12 people/h/stream bank, $n = 25$). The levels of disturbance were based on the number of tourists visiting the study areas. For each rate, 15 transects were at Peguerinos, and 10 at Valsaín. More transects were established at Peguerinos, because of the higher frog densities. Human disturbance rates were created using volunteers and manipulating the number of people walking along each stream bank and the intervals between them (for a similar approach in birds see Fernández-Juricic et al., 2003). During these experiments, people who approached the transects were informed about the study and diverted from the stream banks. If a person entered a transect despite our efforts to prevent it, we discarded the sample.

Immediately after the simulated disturbance sessions, we measured stream bank use by frogs by searching both stream banks of the stream transect thoroughly and recording the number of individuals present within 2 m of the water margin. Every 30 m along each transect, we recorded confounding variables similar to the ones measured before: tree cover, stream width, slope, and elevation.

2.7. Statistical analysis

All variables were checked for normality and homogeneity of variance before running the analyses. The following variables were log-transformed: frog abundance, distance to the nearest road, distance to the nearest recreational area, stream width, and FID.

In assessing the effects of geographic location, environmental conditions, and distance to sources of human disturbance on Iberian frog abundances, we ran a generalized linear model (GLM). From the whole set of independent variables, we excluded iteratively those that showed a significant correlation (e.g., redundant factors). The final model included discrete (location) and continuous variables (altitude, stream width, temperature, humidity, distance to the nearest road, distance to the nearest recreational area). We used a log link function, with a normally distributed response variable. The Wald test was used to evaluate the contribution of each factor to the overall model, and was tested against a χ^2 distribution.

We analyzed the behavioral responses to human approaches considering the effects of micro-habitat variation. Habitat structure variables (% cover of silt, sand, stone, herb and tree, and mean herb and shrub height) were included in a Principal Component Analysis to reduce the number of independent factors. Only those PCA factors with eigenvalues >1 were selected (Kaiser criterion). Two response variables were studied in relation to the number of times the frogs were approached: FID and time to resume pre-disturbance activities. From the set of independent variables available, we excluded iteratively those that showed a significant correlation. A GLM was used, considering the number of times a location with a frog was disturbed (three levels, 1, 2, 3) and the following continuous variables: PCA factors, stream width, temperature, and humidity. When analyzing FID, the dependent variable was continuous (normal distribution, log link function), but when analyzing time to resume pre-disturbance activites, the dependent variable was discrete (multinomial distribution, logit link function). We presented the results of Wald tests, as explained before. We used a Spearman-rank correlation to evaluate the relationship between FID and the time to resume pre-disturbance activities.

Finally, we also used a GLM to evaluate the relationship between the simulated levels of visitor rates and stream bank use by Iberian frogs. Altitude, humidity, and tree cover were incorporated as independent continuous variables. In the final analysis, we excluded independent variables that were significantly correlated to reduce redundancy. We assumed a normal distribution and used log link function. We reported the results of Wald tests.

3. Results

3.1. Iberian frog abundance

Iberian frog abundance was significantly affected mainly by study site location and distance to the nearest recreational area (range = 125–3275 m, Table 1). Abundances were higher in Peguerinos (2.73 ± 0.35), the area with fewer visitors, than in Valsaín (1.15 ± 0.30). Moreover, frog abundance decreased as the distance between recreational areas and streams decreased. No differences in the abundance of frogs were found between stream banks during the surveys (right stream bank,

Table 1
Effects of location, environmental conditions, and distance to the source of disturbance on the abundance of Iberian frogs in the Guadarrama Mountains (Madrid, Spain)

	Coefficient estimate	SE	χ^2	P
Intercept	−4.31	2.62	2.71	0.099
Location	0.40	0.13	8.93	**0.002**
Temperature	−0.01	0.01	0.01	0.980
Humidity	0.01	0.01	1.17	0.278
Altitude	−0.01	0.01	0.12	0.733
Stream width	0.01	0.01	1.16	0.282
Distance to the nearest recreational area	1.25	0.63	3.93	**0.047**
Distance to the nearest road	−0.17	0.22	0.57	0.452

χ^2, Wald statistic; SE, standard error of the coefficient; degrees of freedom = 1 for all parameters. Significant factors in bold.

1.23 ± 1.11; left stream bank, 1.09 ± 0.91; $t = 0.58$, df = 68, $P = 0.560$). Frog abundance was unaffected by distance to roads (range = 50–3275 m, Table 1).

3.2. Effects of repeated disturbance on individual responses

Vegetation structure variables were reduced to three significant components (% total variance explained; PC1, 35.39%; PC2, 22.99%; PC3, 17.44%). PC1 could be considered a gradient from areas with high stone cover (factor loading = 0.89) to areas with a more complex structure of herbs: greater herb cover (factor loading = −0.86) and herb height (factor loading = −0.65). PC2 correlated negatively with sand cover (factor loading = −0.76) and silt cover (factor loading = −0.81). Finally, PC3 was negatively correlated with tree cover (factor loading = −0.89).

The mean FID of Iberian frogs was estimated as 1.01 ± 0.55 m. There was no statistical variation in the distance at which frogs flushed with repeated approaches (first approach, 1.06 ± 0.59 m; second approach, 1.04 ± 0.58 m; third approach, 0.92 ± 0.47 m; Table 2). Habitat structure, but not environmental factors, affected FID. PC1 and PC3 were positively associated with FID, which increased with increasing stone cover and decreasing herb cover and height, and decreasing tree cover. Hence, Iberian frogs flushed earlier in areas with less vegetation cover.

The number of approaches did affect the time to resume pre-disturbance activities (Table 3), with second and third approaches increasing the time it took frogs to reoccupy the disturbed spot (Fig. 1). None of the other habitat structure and environmental factors exerted a significant influence.

There was no significant relationship between the distance at which frogs flushed and the time to reoccupy the disturbed spot (Spearman rank, $r = -0.13$, $P > 0.05$).

3.3. Minimum approaching distance

We estimated minimum approaching distance as 2 m, as 95% of frogs flushed at 2 m or less (Fig. 2). All observed undisturbed frogs were situated less than 0.40 m from the waters edge (mean = 0.24 ± 0.11), so we conservatively assumed that Iberian frogs regularly used the stream bank area up to 0.5 m from the waters edge. Thus, minimum approaching distance should be of, at least, 2.5 m from the stream.

3.4. Stream bank use in relation to manipulations of the frequency of human visitation

Our manipulations of visitor rate did affect stream bank use by Iberian frogs (Table 4). A fivefold increase in the number of visitors per hour reduced stream bank

Table 2
Effects of number of disturbance events, environmental and habitat structure factors on Iberian frog flight initiation distance (FID) in the Guadarrama Mountains (Madrid, Spain)

	df	Coefficient estimate	SE	χ^2	P
Intercept	1	−0.23	1.24	0.03	0.853
Number of disturbance events	2	0.07 0.03	0.08 0.08	1.65	0.439
Temperature	1	−0.01	0.01	0.16	0.692
Humidity	1	0.01	0.01	1.19	0.273
Stream width	1	0.06	0.40	0.03	0.871
PC1	1	0.11	0.05	3.95	**0.047**
PC2	1	−0.05	0.06	0.87	0.351
PC3	1	0.19	0.06	10.49	**0.001**

χ^2, Wald statistic; SE, standard error of the coefficient; df, degrees of freedom. Significant factors in bold.

Table 3
Effects of number of disturbance events, environmental and habitat structure factors on the time to reoccupy the area that was disturbed in the Guadarrama Mountains (Madrid, Spain)

	df	Coefficient estimate	SE	χ^2	*P*
Intercept	3	2.12	5.12	28.77	<0.001
Number of disturbance events	2	1.25	0.37	12.18	**0.002**
		0.06	0.37		
Temperature	1	−0.01	0.01	0.57	0.449
Humidity	1	−0.04	0.02	2.92	0.087
Stream width	1	−0.48	1.60	0.08	0.765
PC1	1	0.14	0.26	0.29	0.587
PC2	1	−0.030	0.261	0.01	0.909
PC3	1	0.183	0.268	0.46	0.495

χ^2, Wald statistic; SE, standard error of the coefficient; df, degrees of freedom. Significant factors in bold.

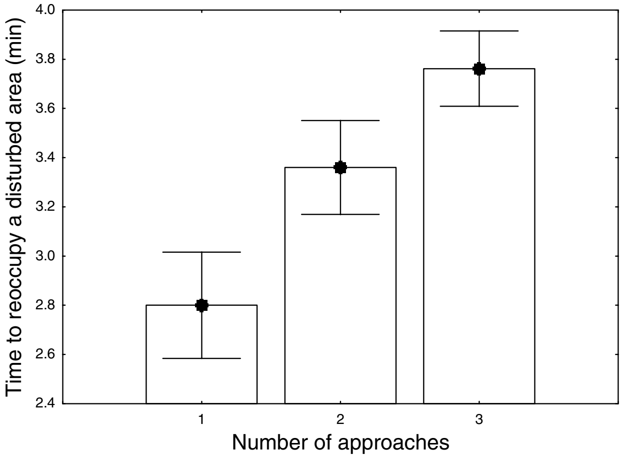

Fig. 1. Mean time (±SE) taken by disturbed Iberian frogs to reoccupy their pre-disturbance areas in the Guadarrama Mountains (Madrid, Spain).

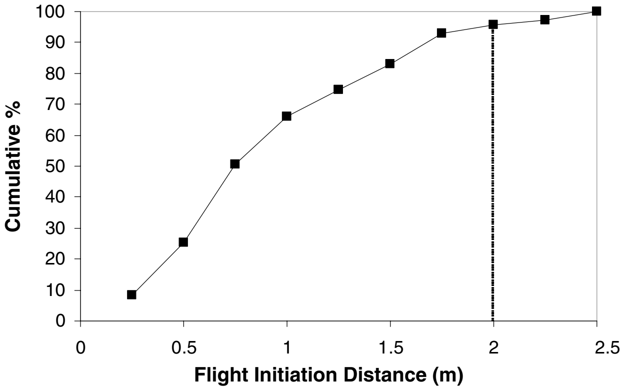

Fig. 2. Estimation of minimum approaching distance for Iberian frogs based on the relationship between the cumulative number of individuals (expressed as percentages) fleeing from humans at different FIDs (flight initiation distances).

use by 80% (Fig. 3); whereas a 12-fold increase, decreased stream bank use by 100%. No other studied factor exerted a significant influence (Table 4).

Given the differences detected in abundance between study areas (see Section 3.1), we assessed whether there would be a differential effect of simulated direct disturbance rates and study area. We found no interaction between both factors ($F_{2,69} = 1.96$, $P = 0.148$).

4. Discussion

Our main results show that: (a) Iberian frog abundance was indeed affected by the proximity to recreational areas, (b) the time to resume pre-disturbance activities increased with the number of disturbance events, but no statistical effect was found on FID in the populations we sampled, and (c) a decrease in the intervals between disturbance events reduced resource use. Overall, these results represent the first empirical support of the resource-use disturbance trade-off hypothesis in taxa other than birds.

The decrease in Iberian frog abundance with the proximity to recreational areas suggests that direct human disturbance affects this species at the population level. The lack of a relationship between the distance to roads and frog abundance may be explained by the year-round site fidelity of the Iberian frogs (García-París, 1985), which do not perform lengthy migrations between breeding, feeding, and overwintering habitats, and therefore are less likely to encounter roads.

The individual responses of Iberian frogs to human approaches were consistent with anti-predator behavior optimization theory (Ydenberg and Dill, 1986; Lima and Dill, 1990; Lima, 1998), by which some animals react to humans as if they were potential predators (Frid and Dill, 2002). Flight initiation distances were shorter with greater herb cover and herb height, which may be explained by a reduction in the perceived risk of predation. Alternatively, frogs may have reduced visibility in high vegetation and high cover so that they do not see a threat until it is closer to them. Similar relationships between vegetation structure and perceived risk of predation have been found in other taxa, such as lizards (Snell et al., 1988; Cooper, 1998; Martín and López,

Table 4
Effects of the simulated visitor rate, environmental and habitat structure factors on the abundance of Iberian frog in the Guadarrama Mountains (Madrid, Spain)

	df	Coefficient estimate	SE	χ^2	*P*
Intercept	1	−6.21	896.64	0.01	0.995
Visitor rate	2	4.41	896.64	25.01	**<0.001**
		2.83	896.64		
Altitude	1	−0.01	0.01	0.01	0.960
Humidity	1	0.01	0.01	1.29	0.257
Tree cover	1	0.01	0.01	2.12	0.145

χ^2, Wald statistic; SE, standard error of the coefficient; df, degrees of freedom. Significant factors in bold.

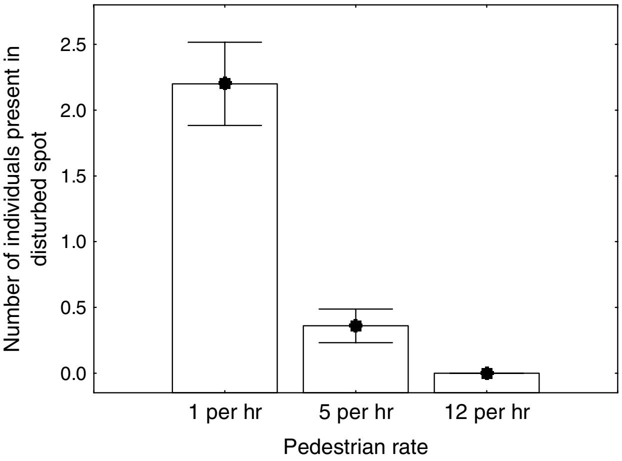

Fig. 3. Mean number of Iberian frogs detected in disturbed plots (±SE) in relation to three levels of simulated visitor rates along stream banks in the Guadarrama Mountains (Madrid, Spain).

1995, 2000). Reduced FID with increasing tree cover can be interpreted by greater shading, which may make an animal harder to detect than in a brighter patch (Wolfe and Summerlin, 1989; Carrascal et al., 2001). These findings suggest that Iberian frog responses to humans may vary with habitat structure in predictable ways; for instance, individuals would be less tolerant of humans in areas with few trees and low herbaceous cover.

With the repetition of disturbance events, Iberian frogs did not vary significantly the distance at which they flushed from the observer; which suggests that habituation was not prevalent in our system. However, our results are not conclusive and longer sampling schemes may be necessary to rule out habituation effects across seasons. A recent study on marmots indicates that habituation to human disturbance may be difficult to detect due to the interaction between behavioral responses, individual variation, and experience (Runyan and Blumstein, in press). More studies are needed in other non-vulnerable species to confirm this. However, Iberian frogs did increase the time to resume pre-disturbance activities with increasing disturbance events. The use of submerged refuges has antipredatory benefits, but at the same time results in a temporal loss of access to terrestrial resources, and thus the decision as to when to emerge is expected to be optimized (Sih et al., 1988; Sih, 1997; Martín and López, 1999). We can interpret our results as stream banks being increasingly risky for frogs with each new successive disturbance event (Cooper, 1997; Martín and López, 2001, 2003), which resulted in greater delays in leaving cover (Martín and López, 2001). It should also be noted that Iberian frog responses may be non-linear (see also Polo et al., in press); thus, linear increments in visitor rates could rapidly decrease access to the stream banks, which could result in cumulative disturbance effects.

By simulating different levels of human visitation along stream banks, we found a decrease in stream bank use (>80%) with direct disturbance rates greater than 5 visitors per hour, which may be explained by the increasing time to resume pre-disturbance activities as the intervals between visitors decreased. According to the resource-use disturbance trade-off hypothesis (Fernández-Juricic, 2000), such increase in human disturbance represents a loss in the spatial and temporal availability of resources for frogs. Our manipulations were done over short periods of time, but future research should determine whether these potential negative effects could become prevalent if recreational activities continue to increase in areas of conservation concern due to the restricted distribution of this species or frogs might eventually adapt. Our evidence suggests the former.

4.1. Management implications

According to our results, we predict that a management scenario that would not compromise the abundance of Iberian frogs and the quality of recreational activities would involve setting up buffer areas of at least 2.5 m from the streams. However, it might not be logistically possible to prevent people from accessing stream banks. If that is the case, we recommend that visitor rates be lower than 5 visits per hour (note that this would allow for more than 5 recreationists per hour if they are grouped in less than 5 groups). A combination of both recommendations could also be feasible by the zonation of stream banks, such that visitors are allowed access to the water in areas of low quality for frogs with rates lower than 5 visits per hour, and buffer areas are established in high-quality areas for frogs using native hedges. The restrictions could be lifted in winter as frogs are inactive in many areas at this time (García-París, 1985). These recommendations, along with environmental education programs, would become more relevant for the conservation of this endemic species when the Guadarrama Mountains are declared a National Park, with a resulting increase in tourists.

Overall, our results suggest that direct human disturbance needs to be considered as a potential factor affecting amphibian populations with low tolerance to disturbance and that the resource-use disturbance trade-off hypothesis can be used as a framework for designing and assessing species-specific management strategies that seek coexistence between wildlife and tourism.

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