| MUNIBE (Suplemento/Gehigarria) | nº 25 | 94-103 | DONOSTIA-SAN SEBASTIÁN | 2007 | D.L. SS-1108/07 |
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# Ecology of amphibians in small coastal Holocene islands: local adaptations and the effect of exotic tree plantations

## Ecología de los anfibios en pequeñas islas costeras del Holoceno: adaptaciones locales y el efecto de plantaciones de árboles exóticos

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**ABSTRACT**

Oceanic islands are rarely colonised by amphibians. Therefore, island populations of this group of freshwater vertebrates are of great evolutionary and conservation interest. In the National Park "Atlantic Islands of Galicia" three species of amphibians have been recorded. The aims of this paper are to estimate population size and local adaptations, and to identify threats and to propose management actions. To this end, field work was done during 2004-06, visiting all the main islands. Individuals were measured, photographed and released. Results confirm previous records that indicated that *S. salamandra* was likely extinct in the Northern islands of Cíes archipelago, and *D. galganoi* in this entire archipelago. By estimating salamander density during nocturnal transects in different habitats at Ons island, we show that the abundance of *S. salamandra* is negatively affected by eucalypt plantations. These exotic tree plantations have destroyed most of the surface of Cíes archipelago, and produced the desiccation of streams, and are the most probable cause of extinction of amphibians. In the other archipelagos, exotic tree plantations are not widespread, and amphibian situation is consequently better. Water availability in Ons is nevertheless restricted by human use of the springs. Our morphological results indicate that island amphibian populations have differentiated from the mainland, and this occurred since the rising of the sea level in the last glaciation (about 10,000 years ago) and are therefore significant units for conservation. We propose simple and cheap measures to minimize human impacts on these fragile populations, and maintain insular amphibian populations for the future.

**KEY WORDS:** Island ecology, amphibian, local adaptation, impacts of forestry, exotic species.

**RESUMEN**

Las islas oceánicas raramente están colonizadas por anfibios. Por lo tanto, las poblaciones insulares de este grupo de vertebrados de agua dulce son de gran interés evolutivo y de conservación. En el Parque Nacional "Islas Atlánticas de Galicia" han sido registradas tres especies de anfibios. Los objetivos de este artículo son hacer una estimación del tamaño poblacional y de las adaptaciones locales, así como identificar las amenazas y proponer acciones de gestión. Con este fin, se realizó un trabajo de campo durante entre 2004-06, visitando las principales islas. Los individuos fueron medidos, fotografiados y puestos de nuevo en libertad. Los resultados confirman los registros anteriores que indicaban que *S. salamandra* probablemente se había extinguido en las islas del norte del archipiélago Cíes, y *D. galganoi* en todo el archipiélago. Estimando la densidad de salamandras durante los transectos nocturnos en los diferentes hábitats de la isla de Ons, demostramos que la abundancia de *S. salamandra* se encuentra negativamente afectada por las plantaciones de eucaliptos. Estas plantaciones de árboles exóticos han destruido la mayor parte de la superficie del archipiélago Cíes y han provocado el desecamiento de los arroyos, siendo la causa más probable de la extinción de los anfibios. Las plantaciones de árboles exóticos no se han extendido a otros archipiélagos, y en consecuencia la situación de los anfibios es mejor. Sin embargo, en Ons la disponibilidad del agua es limitada debido al uso humano de los manantiales. Nuestros resultados morfológicos indican que las poblaciones de anfibios insulares se han diferenciado de las del continente, y esto sucedió desde el aumento del nivel de las aguas en la última glaciación (hace aproximadamente 10.000 años), y son por tanto unidades isignificativas para la conservación. Proponemos medidas simples y económicas para reducir al mínimo los impactos humanos sobre estas poblaciones frágiles, y mantener así en un futuro las poblaciones insulares anfibias.

**PALABRAS CLAVE:** Ecología isleña, anfibio, adaptación local, impactos de selvicultura, especies exóticas.

**LABURPENA**

Uharte ozeanikoak bakan baino ez dituzte kolonizatzen anfibioek. Beraz, ur gezako ornodun-talde honen uhartetar populazioak interes handikoak dira eboluzioaren eta kontserbazioaren ikuspegitik. "Galizia-ko Uharte Atlantikoak" Parke Nazionalean hiru anfibio-espezie erregistratu dira. Dokumentu honen helburuak poblazioen tamaina eta tokiko egokitzapenak kalkulatzea da, baita mehatxuak identifikatzea eta kudeaketa-proposamenak egitea ere. Hori dela eta, landa-lan bat burutu zen 2004tik 2006ra bitartean, eta uharte nagusiak bisitatu ziren. Indibiduoak neurtu, fotografiatu eta aske utzi ziren berriz. Emaitzek aurreko erregistroak berretsi zituzten, hau da, *S. salamandra* ziur aski desagerturik zegoen Cies artxipelagoko iparraldean, eta *D. galganoi* artxipelago osoan zegoen galduta. Ons uharteko hainbat habitatetan gaueko transektoetan arrabio-dentsitatea kalkulatuz, eukaliptoek *S. salamandra*ren ugaritasunean eragin txarra daukala frogatu genuen. Zuhaitz exotiko hauen basoek Cies artxipelagoaren azalerarik gehiena suntsitu dute, errekak lehortu egin dituzte, eta ia segurutzat jo daiteke anfibioak horregatik desagertu direla. Zuhaitz exotikoen lursailak ez dira zabaldu beste artxipelago batzuetara eta horren ondorioz leku horietan anfibioen egoera hobea da. Ons-en, ordea, ura murrizturik dago gizakien ur-iturrien erabileragatik. Gure emaitza morfologikoek frogatu dutenez, uhartetar anfibioen populazioak eta kontinentekoak desberdinak dira, eta hori horrela izan da azkeneko glaziazioa (duela 10.000 bat urte) gertatu zenetik eta beraz kontserbazio-unitate esanguratsuak dira. Populazio hauskor hauen gaineko giza inpaktuak minimizatzeko eta etorkizunean uhartetar populazioei eusteko neurri erraz eta merkeak proposatzen ditugu.

**GAKO-HITZAK:** Uharte-ekologia, anfibioa, tokiko egokitzapena, basogintzaren inpaktuak, espezie exotikoak.

## INTRODUCTION

Amphibians have obviously a limited ability to colonize new islands due to their intolerance to disperse over salt water barriers. Thus, their presence on the islands has often been explained by vicariance biogeography (GRANT, 1998; BOSSUYT & MILINKOVITCH, 2001; BROWN & GUTTMAN, 2002) although some overseas dispersals have been documented (HEDGES *et al.*, 1992; VENCES *et al.*, 2003). Therefore, most volcanic islands do not have native amphibians (VENCES *et al.*, 2003) and orographic islands, those formed in mountains by the rise on sea level, are generally inhabited by amphibians living in the area before the formation of the island.

The theory of island biogeography has developed a framework to study the species richness of oceanic islands, based on the equilibrium between speciation and extinction rates, and the processes of immigration and emigration (MACARTHUR & WILSON, 1967). Nevertheless, genetic models on island evolution have also consequences on population structure and differentiation, including dwarfism and gigantism (JOHNSON *et al.*, 2000). Much of the divergence between island and source populations date to the colonization event. Across islands, it has been predicted that populations on large islands should be on average more genetically divergent from mainland source populations than those on small islands (JOHNSON *et al.*, 2000).

The National Park "Atlantic Islands of Galicia" is constituted by four archipelagos: Cíes, Ons, Sálvora and Cortegada, formed by the rising of sea level in the last glaciation (VILAS PAZ *et al.*, 2006). The main islands are only 1-2 km from the nearest coast, but the sea barrier seems impassable for amphibians. Nevertheless, three species have been recorded in the last decades: *Salamandra salamandra, Lissotriton boscai* and *Discoglossus galganoi* (GALÁN, 2003a). The aims of this paper are: i) to estimate population size and detect tendencies and local adaptations, and ii) to identify the threats of island amphibian populations and to propose management actions to improve the likelihood that these populations persist in the near future. To this end, field work was done during 2004-06, visiting all the main islands.

## METHODS

### Population status and density

The presence and abundance of amphibians in the islands was investigated from 2004 to 2006 by diurnal and nocturnal samplings. All main islands (figure 1) were visited at least once, except in Cíes archipelago, where we concentrated in the Southern island (San Martiño), because no amphibian has been observed in the remaining two islands since at least 1990 (GALÁN, 2003a). We visited San Martiño island in three occasions, including one night, in February and March 2004 and 2005. This island has no entry port, and this greatly limited our ability to sample there. Sálvora was visited in April 2004 and May 2006. Most of our sampling effort was therefore concentrated at Ons (seven sampling sesions, including three nocturnal samplings), in spring and autumn 2004-2006, because this island has all three amphibians. We did not find amphibians at Cortegada island (one sampling in spring 2004).

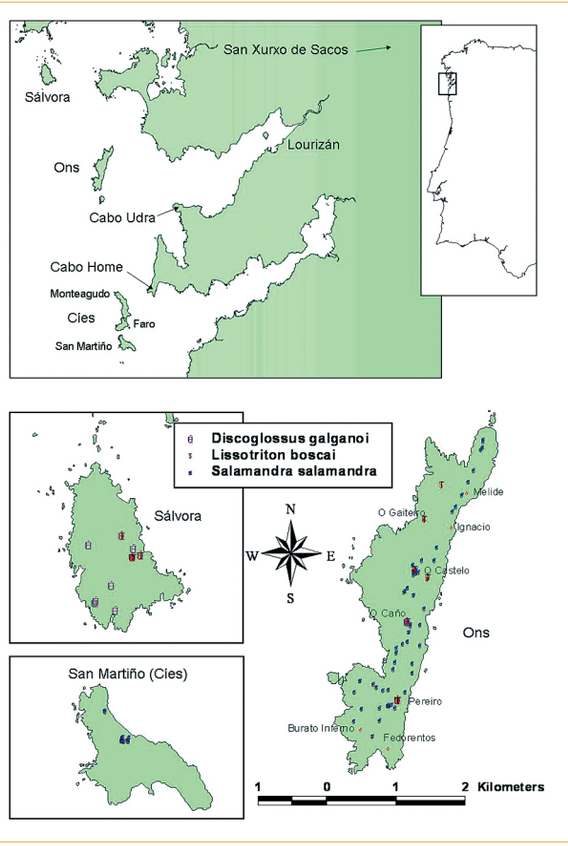


**Figure 1.** Map of the islands of the National Park "Islas atlánticas de Galicia", showing the distribution of amphibians in 2004-2006.

We searched for amphibians under stones and dead wood in favourable microhabitats. All salamanders found in San Martiño were measured, weighted and photographed, and immediately released in the place of capture. Population density was so high in Ons (see Results) that we decided not to take biometrical measurements of all specimens. Larval

*Salamandra*, adult and larval *Lissotriton* and *Discoglossus* were sampled using aquatic nets, and again all individuals found were measured, photographed and released. When possible, a GPS was used to record the position of individuals.

Nocturnal samplings were done to estimate population density of *Salamandra* and *Discoglossus* at Ons, and to localize individuals of *Salamandra* at San Martiño, but in this island transects produced negative results.

We estimated salamander density at Ons by counting the number of individuals found in nocturnal transects in October 2004 and 2006 and March 2005, when climatic conditions were favourable for salamander activity (warm and with drizzle). All transects were done by slowly walking on existing tracks, between 20:30 and 1:30 h. A GPS was used to record the start and end point, and to estimate distance sampled (428 m in average). The number of *S. salamandra* found includes all individuals observed in the path (about 4 m wide), and in the grassy habitats in both ditches. Population density refers to the number of individuals per meter of path. Each transect was categorized in relation to the dominant vegetation, as agricultural land, *Ulex* scrubland and eucalypt plantations. The effect of these main habitat types on *S. salamandra* density was tested using an ANCOVA, including transect length as a covariate. We assume that different estimates of density are independent observations because we never counted the same transect twice on the same night.

### Biometrical study

Measurements were done on alive animals using a digital caliper to the nearest 0.1 mm. For *S. salamandra*, we measured total length (from snout to the end of cloaca), tail length, length and width of the parotid gland, and weight. For *L. boscai* we measured the same variables, excepting parotid glands. Finally, for *D. galganoi,* we measured weight and body length (from snout to cloaca). Populations from the nearest coast (Lourizán, UTM: 29TNG2695, altitude 30 m; Cabo Home, Cangas, UTM: 29TNG1178, altitude 10 m; San Xurxo de Sacos, UTM: 29TNH4006, altitude 200 m) were also sampled to obtain reference data for morphological and ecological comparisons. Sample sizes are indicated in tables I and III.

## RESULTS

### Population status and density

Our results confirm previous studies (GALÁN, 2003a): the island with higher richness of amphibians was Ons (all three species), followed by Sálvora (*L. boscai* and *D. galganoi*) and Cíes (only *S. salamandra* at San Martiño). Figure 1 shows the recent distribution data for all archipelagos. *D. galganoi* seems extinct in Cíes, and *S. salamandra* in the northern islands of this archipelago.

#### *Salamandra salamandra*

This species was rare in San Martiño. We found 13.7 ± 2.4 individuals per visit (for a total of 40 individuals). The second visit in 2004 yielded one recapture (within one month), suggesting very small population size. A nocturnal survey by three observers (20:30 to 23:30) in mid March 2005, yielded not a single record on the favourable habitats, neither on the eucalypt plantation in Concela Valley, the most humid and sheltered habitat. No larvae were found on the stream.

In contrast, all visits to Ons produced at least one record of this species (even visits in mid-July). The species was found in all kind of habitats in this island (figure 1), but is clearly more abundant in areas of *Ulex-Cytisus* scrubland which is the most widespread habitat in this island (figure 2). Maximum density was 0.3 individuals/m (figure 3). We analysed the effect of habitat type on salamander density in nocturnal transects, using an ANCOVA, including transect length as a covariate. The model is highly significant ($F_{3,23} = 7.75$, $p < 0.001$). Results indicate that longer transects had lower density (as expected because they average areas of high and low density; standardized coefficient, b = -0.650, t = -4.32, $p < 0.001$), and the effect of habitat type is significant (using agricultural areas as reference level, *Ulex*, b = 0.199, t = 1.30, p = 0.205; eucalypts, b = -0.327, t = -2.09, p = 0.048). Samples in aquatic habitats produced no larvae (VELO-ANTÓN *et al.*, 2007), and juveniles were found in terrestrial habitats.

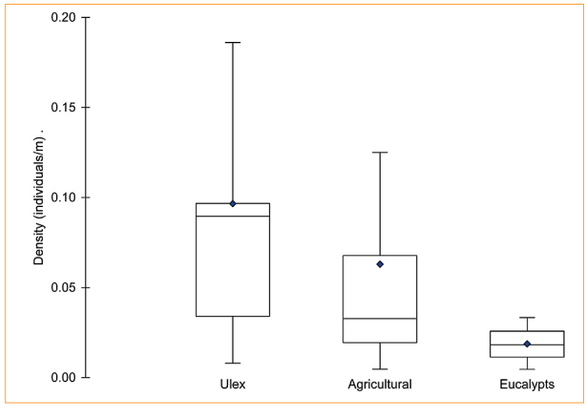


**Figure 2.** The variation in salamander density in nocturnal transects at Ons in relation to dominant vegetation. Ulex: scrubland dominated by *Ulex* and *Cytisus*; Agricultural: pasture lands and grassy fields; Eucalypts: plantations of *Eucalyptus globulus*. The graph shows a box with the 1st quartile, median (horizontal line), mean (diamond), 3rd quartile and both limits (the ends of the "whiskers") beyond which values are considered anomalous.

**Figure 3.** Density of salamanders at Ons island is so high that groups of 2-3 individuals are easily found in nocturnal transects. Picture taken on the night of 31 October 2006.

### *Lissotriton boscai*

Adults and larvae were found in all suitable freshwater habitats in Ons and Sálvora. At Ons, adults were common in the small ponds created by springs. These were associated mostly to washing places: Pereiró, 6.8 ± 2.4 individuals per visit (N=5 visits); O Caño, 13.8 ± 6.5 (5); Cucorno, 3.6 ± 2.1 (5); Melide, 5.5 ± 3.9 (2). At least two suitable places for reproduction are formed at springs, without relationship to washing areas: Fonte do Castelo, 19.0 ± 0.8 (3) and Fonte do Gaiteiro, 4.3 ± 1.8 (3). This last place, a small eutrophic pool (due to the activity of gulls), was covered with stones during 2006, and the habitat was lost. No individuals were found in October 2006 at this place.

At Sálvora, this species seems widespread, but due to the extraordinary dry springs of 2004-2005, the number of individuals found was clearly smaller (in total about 10 adults) than in previous studies (GALÁN, 2003a).

### *Discoglossus galganoi*

During all the sampling trips to the island of San Martiño, we actively searched for eggs, larvae and adults of this species at the suitable habitats in the Concela watercourse. We could not find a single specimen.

At Ons, the species was only found at two small ponds associated to washing places: Pereiró and O Caño. At Pereiró there is a small reproductive population (a maximum density of 10 adults and 12 juveniles observed in a nocturnal sampling in spring 2005; isolated specimens in other samplings). At O Caño only 5 old males (body size between 66 and 78 mm) were found in 2004-2006, suggesting that this local population is about to disappear.

At Sálvora, this species was quite rare in the spring of 2004, a especially dry season (we could only capture 3 individuals), but widespread and common in the spring of 2006, after some weeks with abundant rain (several hundred juveniles observed). Juvenile density at some seasonal wetlands was so high in March 2006, that it was necessary to pay great attention not to walk on them during field work.

## Morphological characteristics

### *Salamandra salamandra*

Island individuals were on average smaller than coastal specimens, especially in San Martiño (table I), confirming previous results based on smaller samples (GALÁN, 2003a). In all cases, males were smaller than females, as is usual in the species (GARCÍA-PARÍS *et al.*, 2004). Body proportions differ among populations: a discriminant analysis, using body length (snout to cloaca), total length (snout to tip of tail) and weight as predictor variables is highly

significant (Wilks' lambda = 0.584, p < 0.001), correctly assigning to the original population between 13% (Cabo Home) and 81% (San Martiño) of specimens (figure 4 and Table II).

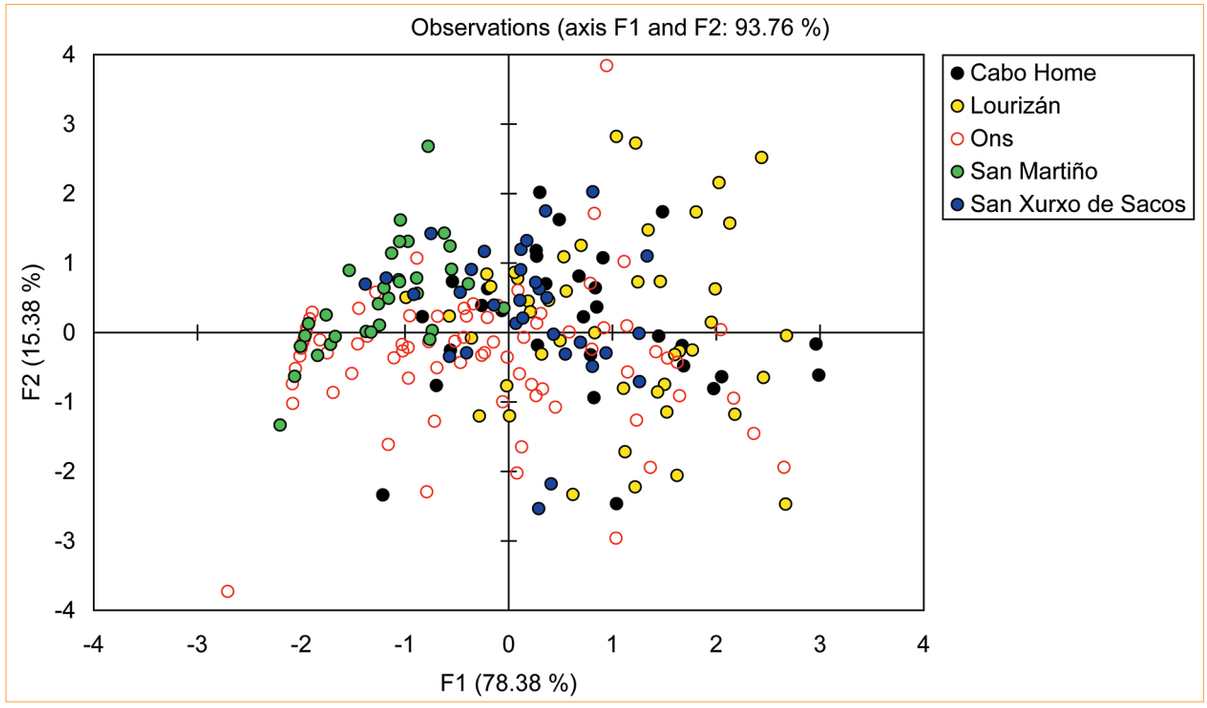


**Figure 4.** Results of a discriminant analysis with body length (head to cloaca), total length (head to tip of tail) and weight as predictor variables. The first axis is a general descriptor of body size, whereas F2 is positively correlated with total length and negatively with weight. Note that San Martiño specimens are clearly different (smaller).

| FEMALES | LHC | LT | LP | WP | WEIGHT |
|---|---|---|---|---|---|
| San Martiño | 83.76±2.54(10) | 134.70±4.24(10) | 9.85±0.50(10) | 4.42±0.16(10) | 13.13±1.16(9) |
| Ons | 102.22±1.19(81) | 159.50±2.00(81) | 12.26±0.29(22) | 5.49±0.16(21) | 27.31±0.95(82) |
| Cabo Home | 112.35±2.92(11) | 176.60±6.01(11) | 12.52±0.40(11) | 5.91±0.23(11) | 35.12±3.10(11) |
| Lourizán | 110.34±1.93(17) | 172.80±3.05(17) | 12.89±0.25(17) | 6.17±0.14(17) | 34.49±1.79(18) |
| San Xurxo de Sacos | 102.01±2.67(14) | 160.40±3.90(14) | 11.96±0.32(14) | 5.54±0.27(14) | 26.56±1.59(13) |
| **MALES** | | | | | |
| San Martiño | 80.35±1.95(14) | 129.60±3.36(14) | 9.16±0.37(14) | 3.94±0.16(14) | 10.07±0.62(11) |
| Ons | 97.54±2.11(36) | 149.00±3.05(37) | 11.06±0.56(5) | 4.75±0.29(4) | 18.89±0.91(29) |
| Cabo Home | 102.66±2.24(19) | 165.50±4.17(19) | 11.17±0.23(19) | 5.20±0.15(19) | 22.93±1.26(18) |
| Lourizán | 100.94±2.06(29) | 164.20±3.97(28) | 12.38±0.29(29) | 5.61±0.14(29) | 26.66±1.51(29) |
| San Xurxo de Sacos | 95.66±2.31(16) | 154.20±3.84(16) | 10.63±0.31(16) | 4.69±0.14(16) | 18.93±1.20(16) |

**Table I.** Morphological characteristics of island and continental populations of *S. salamandra*. Individuals that showed unclear sexual characteristics (in most cases LHC<80 mm), were considered juvenile and are not included in this table. Values are mean±SE (N). LHC= length head-cloaca, LT= total body length, including tail, LP: length of parotid, WP= width of parotid. Measures in mm and g.

| From \ to | San Martiño | Ons | Cabo Home | Lourizán | San Xurxo de Sacos | Total | % correct |
|---|---|---|---|---|---|---|---|
| San Martiño | 26 | 3 | 0 | 0 | 3 | 32 | 81.25 |
| Ons | 10 | 59 | 2 | 20 | 11 | 102 | 57.84 |
| Cabo Home | 2 | 6 | 4 | 12 | 6 | 30 | 13.33 |
| Lourizán | 1 | 9 | 1 | 27 | 7 | 45 | 60.00 |
| San Xurxo de Sacos | 4 | 5 | 1 | 8 | 13 | 31 | 41.94 |
| **Total** | **43** | **82** | **8** | **67** | **40** | **240** | **53.75** |

**Table II.** Confusion matrix for the sample of *S. salamandra* from island and continental populations. Results of a discriminant analysis using body length, length from head to cloaca and weight as predictor variables. Note that island populations are well differentiated.

We compared the size of the parotid glands among populations using an ANCOVA with parotid length as the response variate, population, sex and the interaction population*sex as fixed terms and body length (snout to cloaca) as a covariate. We hypothesized that this trait is related to the predation pressure in each population, and specifically predicted that island populations should have smaller parotids (lower predation pressure). Results indicate that parotid length is indeed different among populations ($F_{1,143}$ = 17.85, p < 0.001), that there are no significant differences between sexes ($F_{1,143}$ = 1.01, p = 0.316), and the interaction term is marginally significant ($F_{4,143}$ = 2.27, p = 0.065). The effect of body size is obviously significant ($F_{1,143}$ = 199.48, p < 0.001). Nevertheless, contrarily to our hypothesis, the smaller parotids were found at the Cabo Home population (where we found the biggest individuals), and the largest parotids, taking into account body size, among Ons and Lourizán specimens (figure 5).

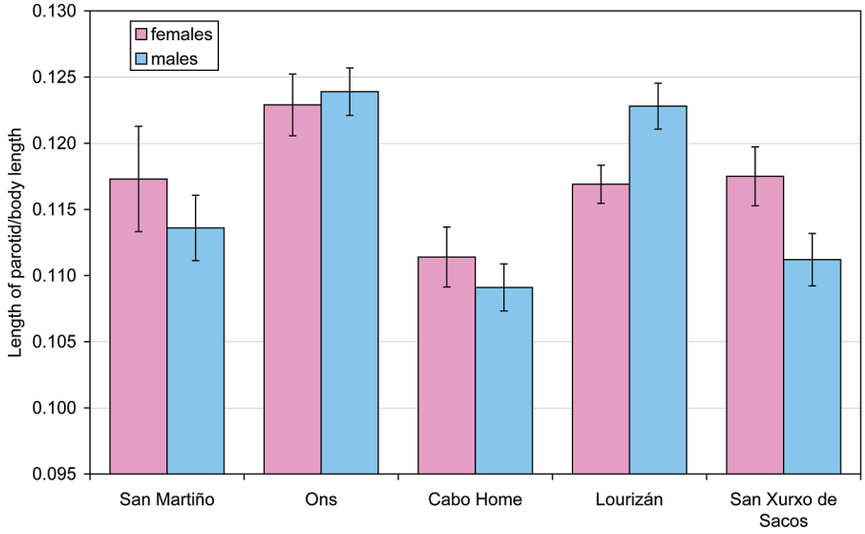


**Figure 5.** The relative size of the parotid glands in island and continental populations of *S. salamandra*. Mean±SE.

### *Lissotriton boscai*

Morphological variables of island and coastal populations are presented in table III. Even if our data are limited, there are clear differences between island and continental populations. As in *S. salamandra*, island specimens of *L. boscai* are smaller than continental ones (ANOVA, total length, Population: $F_{3,132}$=5.17, p=0.002; Sex: $F_{1,132}$=116.95, p<0.001; Population*Sex: $F_{2,132}$=1.54, p=0.219; Length snout-cloaca, Population: $F_{3,131}$=5.77, p<0.001; Sex: $F_{1,131}$=112.39, p<0.001; Population*Sex: $F_{2,131}$=1.96, p=0.145). Adults from Ons weighted on average 1.58±0.10(23) g in the case of females and 1.19±0.04(39) in males. No data are available for other populations.

### *Discoglossus galganoi*

Our data are too scarce for a comprehensive morphological study. For Ons population, the only with available data, the average body length (snout to cloaca) was 57.25±0.75(2) mm in females and 73.61±1.80(16) in males. Weight was 20.65±2.35(2) g in females and 36.31±2.89(10) in males. The maximum weight was 51.0 g for a male, recorded in a very old individual.

## DISCUSSION

### Present and future of island amphibian populations

Our results indicate that amphibian populations in the islands of the National Park “Atlantic Islands of Galicia” are declining in Cíes archipelago, where

| | Length head-cloaca (mm) | | Total length (mm) | |
|---|---|---|---|---|
| **POPULATION** | **FEMALES** | **MALES** | **FEMALES** | **MALES** |
| Ons | 40.35±0.40(45) | 36.23±0.25(63) | 77.29±0.85(44) | 69.12±0.52(63) |
| Sálvora | 40.62±2.94(2) | 35.69±0.84(5) | 79.76±5.95(2) | 68.68±1.50(5) |
| Cabo Home | - | 36.89±0.45(8) | - | 70.97±0.97(8) |
| Cabo Udra | 44.86±0.71(4) | 38.37±0.63(12) | 87.44±2.12(4) | 73.97±1.10(12) |

**Table III.** Morphological characteristics of island and continental populations of *L. boscai*. Values are mean±SE(N).

*D. galganoi* seems extinct and *S. salamandra* has a very small localized population. The situation is stable in the other archipelagos, except for *D. galganoi* at Ons. These results confirm the trends already discussed by GALÁN (2003a). Moreover, these results for *S. Salamandra* are in agreement with preliminary genetic results using microsatellite data (G. Velo-Antón, unpublished) which show a significantly lower genetic diversity in San Martiño island compared to Ons population.

Population density of salamanders is surprisingly high at Ons (GALÁN, 2003a). This could be due to lower predation pressure, because most of the known predators of fire salamanders (*Natrix natrix, Natrix maura, Vipera seoanei, Buteo, Strix, Turdus, Erinaceus, Lutra, Meles, Sus, Mustela*) (GALÁN & FERNÁNDEZ, 1993; SALVADOR & GARCÍA-PARÍS, 2001) are absent from the islands, the exception being *N. maura* and some birds. Although we hypothesized that lower predation pressure could result in smaller parotid glands, the evidence does not support this hypothesis (figure 5).

We have found evidence for a negative effect of intensive forestry in salamander density (figure 2). Eucalypt plantations at Ons and San Martiño islands are the worst habitat for salamanders. The very few specimens observed inside paths on the eucalypt plantations, were found very near to the end of this habitat, suggesting that they came from *Ulex-Cytisus* scrubland. The reason for the scarcity of amphibians in eucalypt plots is likely a combination of the desiccant effect of these trees, that have been widely used to dry-up wetlands (MONTOYA, 1995), and their effect on biodiversity: *E. globulus*, the only species used in these plantations, is toxic for native herbivores, and this determines a drastic effect on insects and other potential prey for amphibians (for a review, see VARELA DÍAZ, 1990). Furthermore, the litterfall from this species has also dramatic effects on the abundance of decomposer fungus and freshwater macroinvertebrates, who die if reared only on eucalypt leaves (GRAÇA *et al.*, 2002). Forestry practices, specially logging have been found to severely affect amphibian populations in other continents (RENKEN *et al.*, 2004), and paradoxically, in Australia, the substitution of eucalypt forest by *Pinus radiata* plantations reduced species richness from 8 to 2 in a frog community (PARRIS & LINDENMAYER, 2004). This is the well-known negative effect of exotic species on native fauna.

On the other hand, the complete extinction of *D. galganoi* at Cíes archipelago, the local extinction of *S. salamandra* at Faro and Monteagudo, and its dramatic situation at San Martiño, is linked to large-scale plantations of *E. globulus*, *Pinus pinaster* and *Pinus radiata* in these islands since 1951 (and to a lesser extent *Acacia melanoxylon* and other invasive trees). Cíes islands were chosen by the foresters to experiment intensive eucalypt plantations, because at that time they were the only state lands available in the province (RICO BOQUETE, 1995). All the preexistent vegetation was destroyed in 280 ha (out of a total of 433 ha), and substituted by these alien species. The effect on water level was very strong: many springs dried-up (GONZÁLEZ-ALEMPARTE FERNÁNDEZ, 2003). Further evidence of this change in water availability is found in San Martiño, an island traditionally used by seamen to obtain drinking water: the spring of Concela is mentioned in several writings of the XVII and XVIII centuries as the best place where to obtain water (GONZÁLEZ-ALEMPARTE FERNÁNDEZ, 2003), and it was so important as to have two water-mills (figure 6). Now this spring dries-up even in winter, and has no water at all in most of its length. The small salamander population remaining in this island is found in the most humid places of the Concela valley, away from the eucalypt plantations, and has clearly survived because it does not reproduce on water, but gives birth to juvenile specimens in land (GALÁN, 2003a; VELO-ANTÓN *et al.*, 2007).

**Figure 6.** The island of San Martiño had an important stream at the Concela valley, which was so fast-flowing as to support two mills. Nevertheless, this stream was dried-up by the eucalypt plantations made in the 1950s. Water-mill and a detail of the millstone of the Concela valley. Some authors consider it the remnants of a blacksmith (Luaces Anca & Toscano Novella, 1998).

The situation at Ons and Sálvora is completely different, because eucalypt plantations are covering just a small proportion of the land. Water availability in Ons is nevertheless restricted by human use of the springs. Most were transformed to washing areas during the 1960's, but in 2004-2006 only the Pereiró spring was used for this purpose (producing sometimes mortality of newts). During 2006 the small pool at Fonte do Gaiteiro was destroyed to allow an easy approach to the spring by visitors. The local population of *L. boscai* was annihilated. Many springs were covered by concrete walls, making them unsuitable for amphibians all over the year. The best situation is found at Sálvora, where most of water points remain in a natural state (GALÁN, 2003a).

**Morphological differentiation and local adaptation**

Our morphological results indicate that island amphibian populations have slightly differentiated from the mainland, and this occurred since the rising of the sea level in the last glaciation (about 10,000 years ago, or even more; VILAS PAZ *et al*. (2006). In this short time-span, salamanders have become viviparous, likely because the scarcity of water was favourable to this reproductive mode (GALÁN, 2003a; VELO-ANTÓN *et al*., 2007). Preliminary genetic analyses indicate that island populations of *L. boscai* and *D. galganoi* are similar to coastal populations (G. VELO-ANTÓN, unpublished results).

*S. salamandra* and *L. boscai* from the islands are significantly smaller than coastal populations. For instance, only 2.6% of *S. salamandra* found in our samples at Ons measured more than 190 mm (total length, including tail), but this percentage was 15.6% at Cabo Home and 8.9% at Lourizán. Only the population of San Xurxo de Sacos was similar to island populations in body size, perhaps due to the fact that this population lives in the remnants of a riparian forest, now almost disappeared and converted into eucalypt plantations. It is possible that food limitation in such suboptimal habitat can determine smaller body size. This dwarfism is a common phenomenon in island populations of many animals (HAYASHI, 1990; ANDERSON & HANDLEY, 2002), sometimes combined with gigantism (GALÁN, 2003b; KEOGH *et al*., 2005). Insular populations are therefore of special conservation concern, given their morphological and genetic differences. In fact, we have proposed that *S. salamandra* from these islands be considered as management units for conservation (VELO-ANTÓN *et al*., 2007).

Populations of *D. galganoi* from Ons and Sálvora do not show dwarfism (GALÁN, 2003a), but we recorded some cases of gigantism, likely due to very old age, among males from Ons. This evidence, combined with previous studies (GALÁN, 2003a), indicates that this species is in a critical situation at Ons, and has disappeared from Cíes.

**Management recommendations**

The main aim of this study was to describe the situation of island populations of amphibians, to identify threats and to propose management strategies for the future. We can summarize the main threats as follows:

- Destruction of habitats for reproduction, by covering springs with concrete walls, inaccessible to amphibians,
- Destruction of adult habitats by intensive silviculture, with exotic species (mainly *Eucalyptus, Acacia* and *Pinus*).

The use of water, a scarce resource in these islands (CARBALLEIRA *et al*., 1983), is the main source of conflicts with human needs. Fortunately, amphibians need water pools for reproduction during spring, well before the tourist activities start. Therefore, our first recommendation is to maintain the small pools now available, and to construct new ones where possible. To avoid the likely extinction of *D. galganoi* in Ons, great care should be dedicated to the O Caño and Pereiró springs, the only ones that now have adequate places for the reproduction of this species. The stream at Melide, that has a washing place in disuse, should be modified to make it appropriate for *D. galganoi* reproduction, by the demolition of the construction and creation of a small pool. This would also benefit the local population of *L. boscai*. Larvae of *D. galganoi* should be transferred to this new pool in the next years, using Pereiró as the source population.

Even if habitat management measures arrive too late for *D. galganoi* at Cíes archipelago, the small population of *S. salamandra* remaining at San Martiño is in urgent need of help. The main recommendation is to eliminate eucalypts, acacias and to a lesser degree pines. The area of Concela valley is the core area of distribution of this species. The eucalypts should be eliminated first from this area, but in successive actuations, to avoid damage to the salamander population.

Finally, most springs have been closed with concrete walls at Cíes, and a large proportion at Ons (GALÁN, 2003a). Where possible, these constructions should be managed to produce a small pool. The spring of O Gaiteiro is a clear example. It had a small pool where *L. boscai* reproduced, but the pool was destroyed to allow an easy approach of tourists to the spring. We think that both uses are compatible, and therefore suggest to revert the situation of this spring, regenerating the pool, and creating stepping stones for visitors.

In conclusion, our results confirm the tendencies detected by GALÁN (2003): the situation is very bad at Cíes, rather good at Ons and good at Sálvora. Simple and cheap measures as the above proposed would be useful to minimize human impacts on these fragile populations, and maintain insular amphibian populations for the future.

## ACKNOWLEDGEMENTS

This research was founded by the Spanish Ministry of Environment, Organismo Autónomo Parques Nacionales (grant 072B/2002). We thank all the staff at the different islands for their help during these years.

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