



Potential impact of climate warming on the distribution of the Golden-striped salamander, *Chioglossa lusitana*, on the Iberian Peninsula

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Abstract. The increase in the concentration of greenhouse gases in the atmosphere is expected to impact the world's climate on a time-scale of just decades. We simulated the potential impact of climate warming on the range of the Iberian endemic Golden-striped salamander, *Chioglossa lusitana*, by extrapolating present-day GIS-based distribution models. The results indicated a significant decrease in the distribution of the species for 2050 and 2080, with losses ranging from 19 to 35% in Portugal and from 17 to 22% in Spain. The models also predict the fragmentation of the species range, in a pattern mirroring past distributions inferred from the spatial analysis of genetic data.

Key words: *Chioglossa lusitana*, Climate change, Distribution, GIS, Generalised linear models, Spatial modelling

Introduction

Over the last two centuries, man's activity has provoked a significant increase in atmospheric concentrations of greenhouse gases, such as carbon dioxide, methane, nitric oxide, ozone and CFCs. This increase is held responsible for the rise in global average surface temperature over the past century (Sandalow and Bowles 2001). Proxy temperature records indicate that the 1990s were the warmest decade of the last one thousand years (IPCC 2001a). As a consequence of the continuing increase of greenhouse gases, a rise by another 1.4–5.8 °C is predicted in the mean global temperature over the next century, with warming more pronounced at higher latitudes (IPCC 2001a).

Natural systems can be specially vulnerable to climate change and some of these systems may undergo significant and irreversible damage (IPCC 2001b). Dramatic changes in vegetation communities are expected to occur as consequence of climate change (e.g. Tchebakova et al. 1995; Sykes et al. 1996; Saetersdal et al. 1998; Crumpacker et al. 2001). This will reflect on the microhabitat and microclimate (Huntley

1995) and impact upon the associated animal communities. Analyses of long-term data sets indicate that the current anomalous climate already affected the physiology, demography, distribution, behaviour and phenology of species (Beebee 1995; Parmesan 1996; Crick and Sparks 1999; Post et al. 1999; Hughes 2000; Gibbs and Breisch 2001).

Evidence from the geological record indicates that the global climate has been changing continuously, but the current rate and magnitude are unparalleled (with the forecasted increase in temperature exceeding that of any period over the last 120 000 years) and it is unclear how species and ecosystems will respond (Graham and Grimm 1990; Huntley 1995; Ennis and Marcus 1996; Hughes 2000). Although in particular cases some genetic changes can occur relatively quickly in response to strong selective pressures (Bradshaw and McNeilly 1991), migration is expected to be the primary response of taxa to climate change (Huntley 1995). Many widespread organisms appear to be limited by temperature, at least in part of their geographic range (Brown and Lomolino 1998). Because a 3 °C change in mean annual temperature corresponds to a shift in isotherms of 300–400 km in latitude or ca. 500 m in altitude (Hughes 2000), drastic changes in species distributions are expected in response to climatic shifts.

Ecological models can be used to synthesise the current knowledge about species requirements and to predict ecosystem dynamics under changed conditions (Shugart 1990). Most simulations to date on the potential consequences of global climatic change are run for plant communities (e.g. Shugart 1990; Sutherst 1995; Tchebakova et al. 1995; Sykes et al. 1996; Saetersdal et al. 1998; Crumpacker et al. 2001) using present-day ecological models. We here use that technique to predict the potential impact of climate change on the distribution of an amphibian. Climate change is expected to strongly affect ectothermal animals, such as amphibians, because temperature directly influences most physiological processes including respiration, reproduction, locomotion and metabolic reactions (Whitford 1973; Feder 1978; Rome et al. 1992; Tripepi et al. 1998). Climatic change was invoked as a key parameter in the global decline of amphibian populations, through e.g. the increase of harmful UV-B radiation to developing embryos (Kiesecker et al. 2001).

Materials and methods

Study organism

The golden-striped salamander, *Chioglossa lusitanica*, is endemic to the Iberian Peninsula. It has a peculiar morphology with a thin body and a long tail corresponding to 2/3 of its total length. The species possesses some unusual characteristics among salamandrids namely the capability of tail autotomy, a protractile tongue and no func-

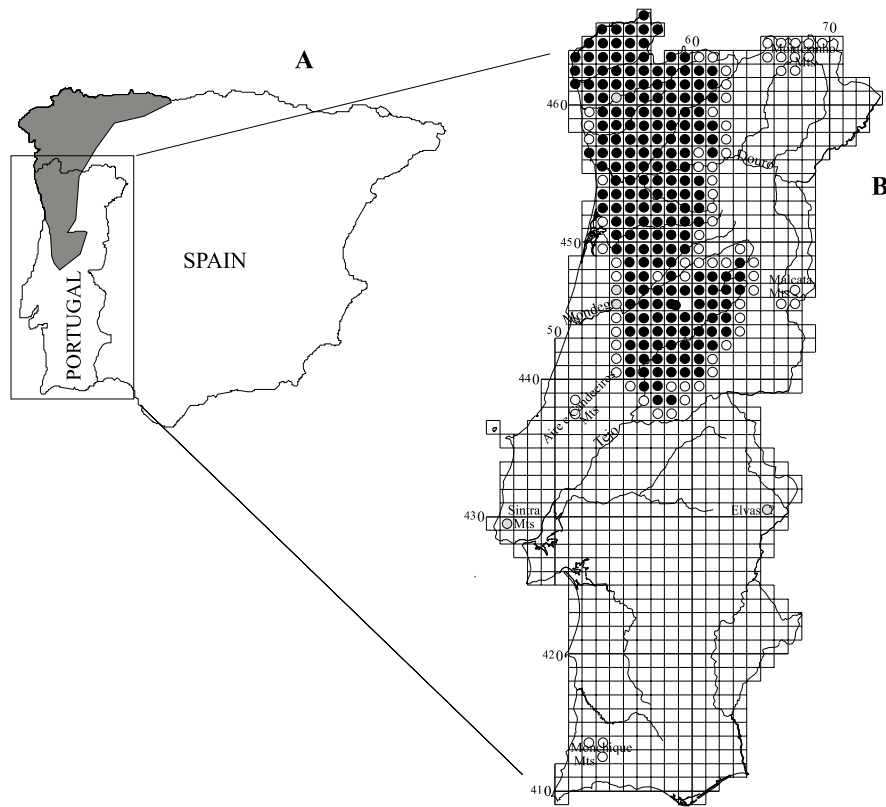


Figure 1. (A) Range of *C. lusitanica* on the Iberian Peninsula (adapted from Arntzen 1999), (B) distribution of *C. lusitanica* in Portugal in UTM 10×10 km squares. Solid dots correspond to observed occurrences, open dots to inferred absences, and grey dots to literature citations covering cells in which the species was not observed (from Teixeira et al. 2001).

tional lungs (Arntzen 1994). *C. lusitanica* is a IUCN Red Data Book listed species and the only actual representative of its genus. The species occurs along swift running streams in humid, mountainous areas. Its range can be described by a small set of environmental parameters including precipitation, slope and mean July temperature (Teixeira et al. 2001). Presence and absence data for *C. lusitanica* were obtained from a countrywide survey of the species in Portugal, with a 10 km spatial resolution (Figure 1).

Environmental data and analysis

Thirteen environmental parameters used for spatial modelling are presented in Table 1. Parameter selection was as in Teixeira et al. (2001). Biological and environmental data were used as respectively dependent and independent variables in logistic regression (Logit R) and discriminant analysis (DA), with SPSS v. 8.0 for Windows

Table 1. Environmental parameters used to model the distribution of *C. lusitanica* in Portugal.

Variable	Code	Available for Spain	G-test	Sources
Acidity of the soil (pH)	ACID	No	482.5	DGA (1995)
Altitude (m)	ALTI	Yes	128.0	USGS (2001)
Frost days (number)	FROD	Yes	8.8	DGA (1995), IGN (1992)
Frost months (number)	FROM	No	11.3	DGA (1995)
Hardness of subterranean water (CaCO ₃ mg/l)	HARD	No	443.2	DGA (1995)
Humidity of the air (%)	HUMI	Yes	41.0	DGA (1995), IGN (1992)
Insolation (h)	INSO	Yes	548.9	DGA (1995), IGN (1992)
Lithology	LITH	No	217.4	DGA (1995)
Vegetation index	NDVI	Yes	11.9	Courtesy of Royal Dutch Meteorological Institute (KNMI)
Annual total precipitation (mm/year)	PRET	Yes	891.3	DGA (1995), IGN (1992)
Slope (%)	SLOP	Yes	438.1	Produced from ALTI
Annual mean temperature (°C)	TEMP	Yes	399.7	DGA (1995), IGN (1992)
July mean temperature (°C)	TJUL	Yes	574.6	SCN (1974), IGN (1992)

DGA – Direcção Geral do Ambiente; IGN – Instituto Geografico Nacional; SCN – Serviço Climatológico Nacional; USGS – United States Geological Surveys.

(SPSS 1997). Logit R and DA are generalised linear models (GLM) widely used for modelling purposes (e.g. Austin et al. 1996; Corsi et al. 1999; Manel et al. 1999). They are powerful analytical tools, capable of analysing the effects of one or several independent variables, discrete or continuous, over a dichotomous variable (Williams 1983; Hosmer and Lemeshow 1989).

To perform DA, distributions of variables were tested for normality using the Kolmogorov–Smirnov test. All variables were subjected to three transformations – logarithmic, square and Box-Cox. For each variable, the transformation that produced the highest *P*-value was retained (see Teixeira 1999 for details).

Individual variables were tested for explanatory power with *G*-statistics in univariate logistic regression analysis. Variables were selected to the models by a forward stepwise addition procedure with Bonferroni's correction to the initial threshold of 0.05. The sequence of variables in the derived equations from both methods represents their order of entrance in the models. The performance of the models was evaluated through Cohen's κ statistic and correct classification scores (CCS). Cohen's κ is a measure of the proportion of all possible cases of presence or absence that are predicted correctly after accounting for chance effects, and provides a simple, effective, standardised and appropriate statistic for evaluating or comparing presence-absence models (Manel et al. 2001). For map making, selected variables were introduced into the Geographical Information System Idrisi v. 2.007 (Eastman 1997) as raster layers with a spatial resolution of 1 km.

Additional analyses were done on the basis of the nine environmental variables for which data were available for Spain (Table 1, IGN 1992) to allow the extrapolation of

the models to that country. Because the knowledge of the species distribution in Spain is not numerically well documented, we used the range of the salamander (Arntzen 1999) to evaluate model fit.

Simulations of the effects of climate change on *C. lusitanica* were based on the HadCM2 Global Change Models (GCM), available at IPCC (2001c). These models predict a rise of 2 °C in annual and July mean temperature for 2050, and of 3 °C for 2080. No significant changes in precipitation are predicted for the Iberian Peninsula over this period. HadCM2 models have an equilibrium climate sensitivity (i.e. the global-mean temperature response to a doubling of effective CO₂ concentration) which is somewhat lower than most other GCMs (IPCC 1999).

Results

For Portugal, the Logit R-based model included five variables, as follows: $g(x) = 5.499 + 0.009\text{PRET} - 0.687\text{HARD} - 0.799\text{FROM} + 0.082\text{SLOP} - 0.594\text{TJUL}$. The DA-based model included six variables, as follows: $z(x) = 5.776 - 0.117\text{ACID} - 1.343\text{ALTIBOX} + 0.016\text{SLOP} - 1.052\text{LITH}_1 + 0.045\text{PRET} - 0.027\text{TJUL}$. Cohen's κ and CCS were 0.892 and 0.887, and 94.5 and 94.3%, respectively. No marked differences were found in CCS between presences and absences. For either model the descriptive map closely matches the salamander's documented distribution (Figure 2).

Considering the nine environmental variables for which data were available for Spain the models were: $g(x) = -0.017 + 0.009\text{PRET} + 0.131\text{SLOP} - 0.004\text{ALTI} - 0.521\text{TJUL}$ (Logit R) and $z(x) = 1.677 - 0.024\text{PRET} - 0.024\text{TJUL}$ (DA). Cohen's κ and CCS were 0.860 and 0.850, and 92.9 and 92.7%, respectively. The applications of these models in Spain yielded a correct classification of 91.9% (Logit R) and 93.7% (DA). For both models the range predicted for Spain covers the known distribution entirely (Figure 3).

Simulations on the effect of climate change indicated a reduction of the potential range of *C. lusitanica* (defined as a probability of occurrence >50%). For 2050, the decrease in range was 3450 km² (15.1%, Logit R) and 4299 km² (25.3%, DA) in Portugal, and 8117 km² (10.8%, Logit R) and 12 414 km² (13.7%, DA) in Spain (Figure 2). For 2080, predicted decreases were respectively 4919 km² (19.0%) and 6369 km² (34.5%) in Portugal, 9530 km² (16.5%) and 15 092 km² (22.3%) in Spain.

Discussion

Our models indicate that temperature may be a key factor in the biogeography of *C. lusitanica*, although it should be kept in mind that correlation does not necessarily imply causation (James and McCulloch 1990). Models over a 50- to 80-year period with global warming predict a substantial range reduction for *C. lusitanica*. Lower

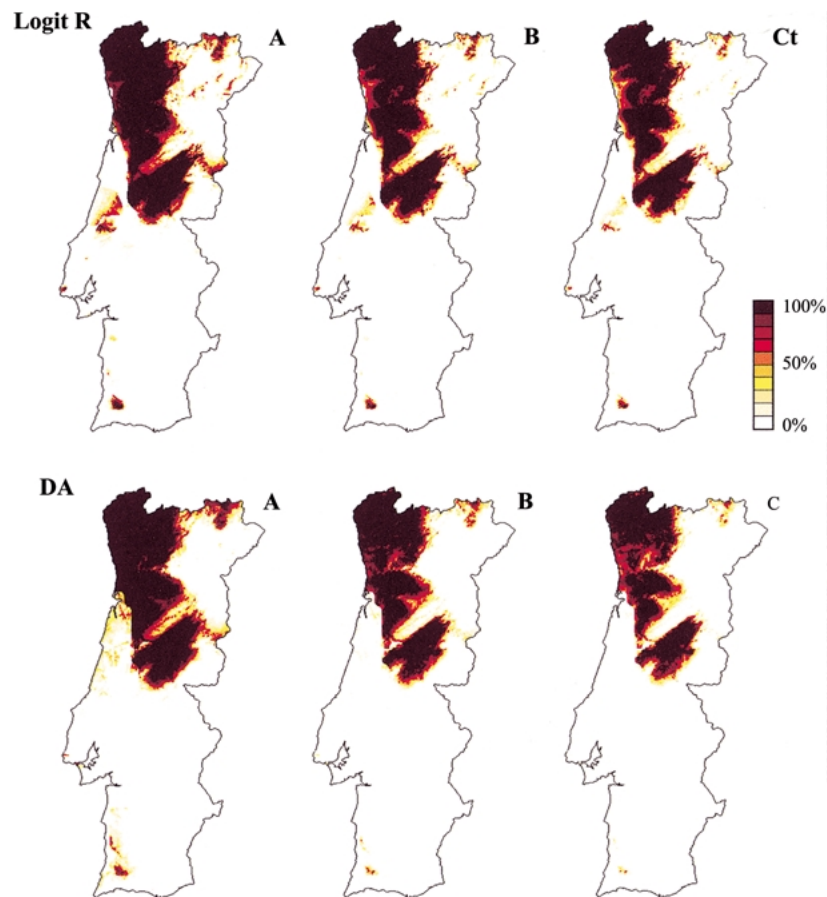


Figure 2. Logistic regression (Logit R) and DA based predictions on the impact of climate change on the range of *C. lusitanica* in Portugal. (A) Present day model, (B) scenario for the year 2050 (increase of 2 °C), (C) scenario for the year 2080 (increase of 3 °C).

altitudes in particular would become less favourable for the species. Our models did not predict a range shift to higher latitudes as was found in many vegetation simulations (Tchebakova et al. 1995; Sykes et al. 1996; Crumpacker et al. 2001). This may be due to the species' dependence on a more complex set of ecological variables, which include geographical parameters, such as slope, and soil-type related characteristics, such as acidity and hardness of water. Interestingly, the predicted reduction in the species distribution implies a range fragmentation in Portugal along the Mondego and Douro rivers. This is coincident with the observed genetic substructure of *C. lusitanica*, supporting a scenario of past allopatry, induced by climatic conditions (Alexandrino et al. 1997, 2000).

Ambient temperature directly or indirectly affects many environmental variables that limit amphibian occurrence, such as soil moisture and air humidity, vegetation

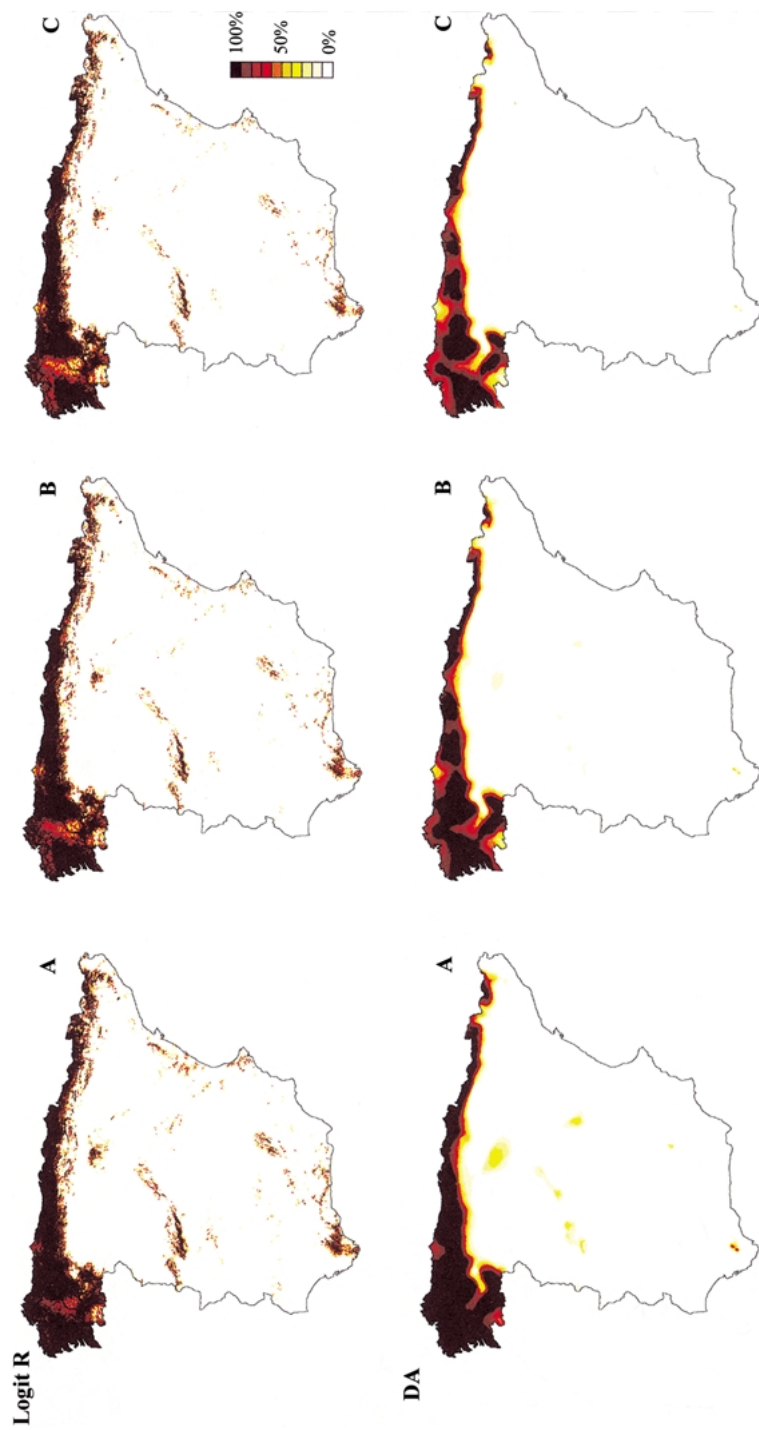


Figure 3. Logistic regression (Logit R) and DA based predictions on the impact of climate change on the range of *C. lusitanica* in Spain. (A) Present day model, (B) scenario for the year 2080 (increase of 2 °C), (C) scenario for the year 2080 (increase of 3 °C).

composition, permanency of brooks and concentration of dissolved oxygen in the water (e.g. Thorson and Svihla 1943; Jaeger 1971; Sugalski and Claussen 1997). *C. lusitanica* seems to be a species sensitive to temperature. It does not normally occur in areas with mean July temperature exceeding 22.5 °C (Teixeira et al. 2001). Goux (1957) reports critical thermal values for *C. lusitanica* in captivity of 28 °C for adults and 25 °C for larvae, which is low compared to other salamandrids, e.g. *Salamandra salamandra*, with a corresponding critical temperature for adults and juveniles of 35 °C (Degani 1994).

The existing debate on the relationship between greenhouse gas emissions and climate change leaves little doubts that both phenomena are linked (IPCC 2001a). Climate change can be responsible for major changes in species distributions due to direct physiological effects – where vegetation and ectothermal animals are the most likely targets –, impacts on the supporting ecosystems, or by inducing the invasion of opportunistic or exotic species (Graham and Grimm 1990; Sutherst 1995; IPCC 2001b). Considering the many possibilities, there is an urgent need for the global assessment of the impact of climate change on species and ecosystems.

The modelling techniques that we used are a simple approach to a complex problem, where several variables may interact with synergetic or opposing effects. Modelling is as yet the only available way to gain insight into the direction and magnitude of the repercussions of environmental change. Even simple models may contribute to an informed conservation planning, through the identification of the expected response of individual species or communities to climate change, the detection of stronghold areas, and towards the development of habitat corridors that allow dispersal to areas that will become suitable in a near future. The models may also assist to alert the public to the potential negative impact of climate change to the natural world and to bring home the message of the urgent reduction in greenhouse gas emissions.

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