SOCIETAS HERPETOLOGICA ITALICA

TILIGHELTA
SHI SEZIONE SARDIGNA

HERPETOLOGIA SARDINIAE

Editor: *Claudia Corti*

EDIZIONI Belvedere

SOCIETAS HERPETOLOGICA ITALICA

7° CONGRESSO NAZIONALE

Oristano, Promozione Studi Universitari Consorzio1, Via Carmine (c/o Chiostro)

1-5 ottobre 2008

Esempio di citazione di un singolo contributo/*How to quote a single contribution*

Angelini C. & Utzeri C., 2008. Survival analysis of two populations of *Salamandrina perspicillata* (pp. 15-17). In: Corti C. (ed.), 2008. Herpetologia Sardiniae. *Societas Herpetologica Italica*/Edizioni Belvedere, Latina, "le scienze" (8), 504 pp.

From introduction to the establishment of alien species: a preliminary analysis of bioclimatic differences between presence and reproduction localities in *Trachemys scripta*.

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Key words: Biological invasions, Bioclimatic envelope, Fitness, Reproduction.

Understanding the factors determining the transition from introduction of aliens to the establishment of invasive populations is a critical issue of the study of biological invasions, and has key implications for management. Differences in fitness among areas of introduction can define the zones where aliens become invasive.

The North American slider turtle *Trachemys scripta* has been traded as a pet and introduced worldwide. Feral individuals are currently present in about 30 countries, and several studies suggested that it can have a negative impact on freshwater ecosystems (Lever, 2003). Nevertheless, most of feral *T. scripta* are actually non reproducing. It is therefore unclear whether this species will originate a biological invasion. In this preliminary analysis, we used ecological modelling to assess the factors influencing the distribution of *T. scripta* in Italy, by analysing bioclimatic features that can cause the transition from presence of feral adults to breeding populations. Moreover, we evaluated whether the ongoing climate change might increase the suitability for reproduction, and boost the risk of establishment and invasion of this species in the near future.

We used the literature, field data and reports from field herpetologists to obtain information on the distribution of *T. scripta* in Italy, and on localities where reproduction occurs. We used the CRU CL 2.0 global data set at 10' × 10' to obtain data on bioclimatic variables (average temperature in January and July; annual solar radiation; annual precipitation). Moreover, we used the human footprint (Sanderson *et al.*, 2002) as a measure of human influence on the landscape.

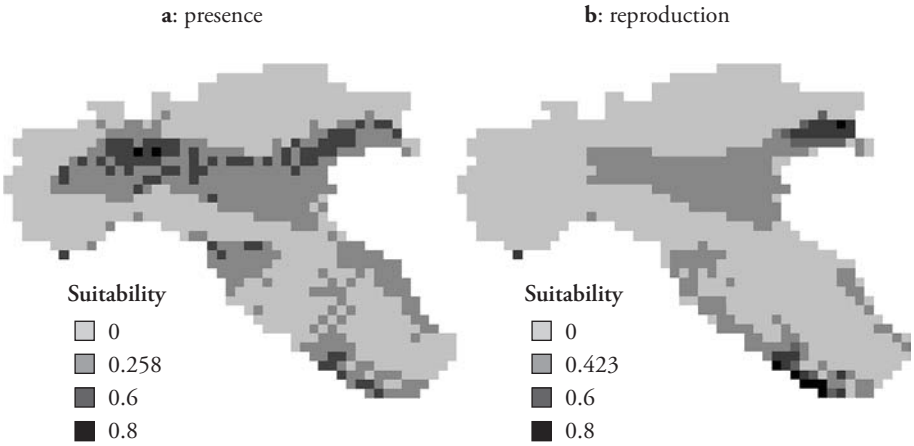

Figure 1. Present day predicted suitability for (a) presence and (b) reproduction of *T. scripta*.

We used maximum entropy modelling (Maxent 3.1: Phillips & Dudík, 2008) to evaluate the relationship between occurrence / reproduction of *T. scripta* and the bioclimatic variables, and to build suitability maps. Moreover, we used a scenario of climate change (scenario A1: Nakicenovic & Swart, 2000) to project the predicted suitability under future climatic conditions (2020).

Feral *T. scripta* was present in 121 10' × 10' pixels. However, reproduction was observed only in a small subset of localities (16 pixels). Bioclimatic features were different among pixels with and without observed reproduction. Pixels with reproduction had higher winter temperature (t-test, $P = 0.009$) and more annual radiation ($P = 0.023$) than pixels were reproduction was not observed. We did not observe significant differences for annual precipitation and human footprint (both $P > 0.75$).

Maxent models showed that feral populations were associated to areas with high summer temperature and human footprint. Furthermore, annual precipitation and solar radiation explained a significant proportion of variance. Reproductive populations were associated to areas with more solar radiation, warmer temperature and more precipitation, while human footprint did not explain a significant proportion of variance. Both models showed a good fit: the AUC of the model obtained from presence data was 0.828, and the AUC of the reproduction model was 0.868.

The areas with the highest suitability for reproduction were different from the areas with the highest probability to find feral *T. scripta* (Fig. 1). Feral *T. scripta* were associated to lowlands and to large cities. Only a smaller proportion

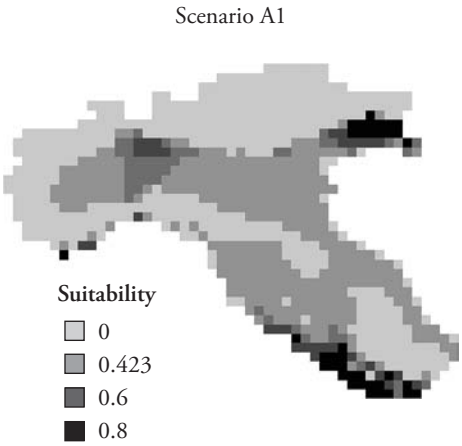

Figure 2. Predicted suitability for reproduction in the future, following the scenario of climate change A1.

of the study area was suitable for reproduction, which was confined mostly to coastal, Mediterranean areas (Fig. 1).

The projection of suitability for reproduction, using the future bioclimatic features predicted under the scenario A1, suggests an increase of suitable areas. This scenario predicted for 2020 an expansion of suitable areas far from the coastline, in the Northern regions and in most of areas where feral *T. scripta* are currently present (Fig. 2). Further analyses are needed to evaluate the predictions obtained under different climatic scenarios (for example, A2, B1 and B2).

This preliminary analysis suggests that, under present-day environmental conditions, the bioclimatic envelope entailed by the presence of feral *T. scripta* is markedly different from the envelope of populations were reproduction actually occurs. This indicates that most of feral *T. scripta* are introduced and survive into suboptimal environment, where bioclimatic conditions currently are not suitable for reproduction. However, lack of reproduction in many feral "populations" does not mean that *T. scripta* will quickly become extinct before establishment. The results of this preliminary analysis suggest that the environmental features required for reproduction are currently present in several areas of Italy with Mediterranean climate (Fig. 1). Further analyses are required to assess the robustness of our models, and their predictive capacity (Pearson *et al.*, 2007; Raes & ter Steege, 2007).

The individuation of a bioclimatic envelope, distinct from the one of non reproductive pixels, indicates that reproduction does not occur in a random subset of presence localities, but is instead related to well defined environmental pa-

rameters necessary for reproductive success. Therefore, we suggest the eradication of *T. scripta* from the areas whit the highest suitability for reproduction, because these areas can become the source of an invasion. Moreover, the ongoing climate change will probably boost the fitness of introduced individuals in the near future. Therefore, even "populations" where reproduction currently does not occurs might become invasive in the near future, and their threat should not be overlooked.

Acknowledgements. We thank an anonymous reviewer for comments on the manuscript.

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