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Decline of a common reptile: case study of the viperine snake *Natrix maura* in a Mediterranean wetland

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Abstract. The Ebro Delta is a wetland area in which natural ecosystems have been partially replaced by rice fields. This mixed and productive landscape has allowed the establishment of a rich community of organisms. The viperine snake *Natrix maura* has traditionally been a common and abundant predator because the habitat is favorable and prey availability is high. In June 1995, we conducted a demographic study to evaluate relative densities of snakes in the rice fields. Thirteen years later, we repeated the same study in the same area and season. The field work consisted of 29 censuses of one hectare each, and snakes and their potential prey (green frogs and fish) were counted. In 1995, we found 27 snakes (0.93 animals/ha), these occupying 48% of the sites. Frogs and fish were observed in 23 of the 29 censuses (79%). In 2008, no snakes were found and frogs and fish appeared in only 11 of the samples (38%). In 2008, we also prospected 20 sites in rice fields located next to the natural lagoons. At these sites, we detected a greater number of snakes (25% of the stations). Several factors can explain the clear decline of the *N. maura* population in the Ebro Delta rice fields: 1) the transformation and degradation of the habitat; 2) the increase in population densities of natural predators such as herons; 3) the decrease in prey availability; 4) the massive use of pollutants in the rice fields; and 5) snake death on local roads and directly by human persecution. We propose that a combined effect of these factors has caused the alarming decline of this predator. The observation of water snakes in rice fields near natural lagoons indicates that protected natural areas act as natural refuges for fauna with reduced mobility, such as viperine snakes. The recovery of the *N. maura* population in the rice fields of the Ebro Delta depends on an integral change in agricultural management, including the reduced use of pollutants, the recovery of snake prey, and the maintenance of favorable habitats to prevent predation.

Keywords. Conservation, habitat loss, Mediterranean, pesticides, population decline, snakes.

INTRODUCTION

The loss of diversity as a result of habitat degradation has been described in diverse taxa (Brooks et al., 2002). Decline in reptiles is associated with several factors, such as the

loss and degradation of habitats, the introduction of alien species, environmental contamination, disease, unsustainable land use, and global climatic change (Gibbons et al., 2000). The detection of population decline in reptiles is difficult because many species register low population densities and there are few long-term studies in natural populations to infer demographic patterns of change or tendencies (Gibbons et al., 2000). These drawbacks are even stronger in the case of snakes, for which basic ecological studies are needed to assess their conservation status (Seigel, 1993; Dodd, 1993). Snakes are susceptible to population decline because they have relatively long lives, they are exclusively carnivorous, and they have low reproductive output (Scott and Seigel, 1992; Dodd, 1993; Fitzgerald et al., 2004). In addition, these reptiles have high mortality rates as a result of human activities (Bonnet et al., 1999; Webb and Shine, 1998). In summary, several life-history traits make snakes useful indicators of habitat quality (Beaupre and Douglas, 2009).

Over centuries, Mediterranean ecosystems have been radically altered by human activity, with drastic changes linked to land use (Blondel and Aronson, 1999). The impact of land use practices on Mediterranean biodiversity has been considerable, and 15% of endemic animal and plant species in the Mediterranean basin (12% of the reptiles) are under threat of extinction (Brooks et al., 2002). Declining reptile biodiversity has been reported in agricultural habitats of NE Iberian Peninsula (Ribeiro et al., 2009). However, in this region, the diverse land uses do not affect species to the same extent, as traditional agriculture characterized by a mosaic of cultures and small patches of natural vegetation maintains high indexes of reptile biodiversity (authors, unpublished data). In fact, snakes can change considerably their dietary habits with habitat alteration, either in the tropics (Luiselli, 2006) or in the Mediterranean basin (Capizzi et al., 2008). At the other extreme, the urbanization of the Mediterranean coastal belt (Greenpeace, 2005) has caused a general decline that affects the entire snake assemblage (Santos et al., 2007).

Natrix maura is a small aquatic snake that forages on fish and amphibians (Santos, 2004). It is a common species in the Western Mediterranean and inhabits natural and artificial water bodies, such as ponds, rivers, streams, dams and marshes (Bons and Geniez, 1996; Naulleau and Schätti, 1997; Santos et al., 2002; Gentilli and Scali, 2006). The dietary habits of this water snake and its capacity to colonize new artificial habitats (Rugiero et al., 2000; Santos, 2004) make it highly adaptable to changes in land use. In addition, *N. maura* can sometimes show high population densities (up to 4800 adults / ha in the river Jalón, Alicante, Spain, Hailey and Davies, 1987b) as long as sufficient prey is available (Hailey and Davies 1987a; Santos, 2004). These demographic and ecological trends make this snake a good model to assess the decline of natural populations. The Mediterranean wetlands are one of the habitats in which *N. maura* shows very dense populations. In Catalonia (NE Iberian Peninsula), the Ebro Delta forms a deltaic platform of 32000 hectares, in which part of the natural vegetation has been replaced by rice fields. The network of canals and rice fields has allowed the development of a dense *N. maura* population which has grown as a result of the high availability of their preferred prey, namely green frogs and fish (Santos et al., 2000). We have evaluated snake-density shifts in the rice fields and discuss the reasons for this change. For this purpose, we conducted censuses in the rice fields during spring 2008, and compared these results with those from censuses made in spring 1995 in the same sites and following the same methodology.

MATERIAL AND METHODS

The Ebro Delta is one of the largest wildlife refuges on the coast of the Iberian Peninsula. It comprises an extensive surface of wetlands, lagoons and natural vegetation. However, the twentieth century was marked by intense agricultural activity dedicated to rice, which, at that time, accounted for 40% of the delta surface area. Far from threatening the wildlife in the delta, rice fields and the network of canals are a good example of how the conservation of the natural patrimony and agricultural activities can be compatible (Fasola and Ruiz, 1996). The rice field system is especially suitable for certain aquatic species, since the rice cycle modulates their phenology through seasonal variation in food availability (Llorente, 1984; Ruiz, 1985; Fasola and Ruiz, 1996). In the Ebro Delta the rice cycle is seasonal: the canals and rice fields are dry from October to April. In April, the canals overflow and are colonized by diverse aquatic fauna (Forés and Comín, 1986; González-Solís et al., 1996). The rice grows until September, when it is harvested. After that, the fields and canals are drained again. The viperine snake *N. maura* is one the commonest non-bird predators in the rice fields of the Ebro Delta. Being an aquatic predator, it forages on fish and frogs while juveniles also forage on invertebrates, newborn fish and tadpoles (Santos, 2004).

N. maura is abundant throughout the Ebro Delta (Llorente et al., 1991). The rice cycle has modified several life-history traits, such as activity (Santos and Llorente, 2001a), reproduction (Santos and Llorente, 2001b; Santos et al., 2005), diet (Santos et al., 2000) and diverse physiological processes (Santos and Llorente, 2004; Santos et al., 2007). Although rice fields provide habitat and prey for *N. maura*, several recent human activities are reducing the quality of this habitat. On the basis of our field work experiment in the Ebro Delta and our knowledge of this species, we hypothesized that the species is undergoing a population decline in the Ebro Delta rice fields. To examine this hypothesis and identify the possible causes, we compared the relative abundance of *N. maura* collected during field censuses made in June 1995 and June 2008.

In each period, field work consisted of 29 censuses during which we searched for snakes in the same area and season, and followed the same methodology to compare the relative abundance between years. In addition, in June 2008 we made 20 censuses in rice fields close to lagoons and natural vegetation in order to assess the effect of wetland proximity to rice fields on snake abundance. Each census was done by searching for snakes in one hectare. The limits of each square were established by means of aerial photographs in 1995 and GPS in 2008. During censuses, we searched for snakes in canals and rice fields, and turned rocks and other materials that often provide refuge to this species. Furthermore, we also recorded the number of green frogs and fish, their usual prey (Santos et al., 2000).

RESULTS

In 1995, we observed 27 snakes in 48% of the censuses (average 0.9 snakes/census; maximum 6 snakes) whereas in 2008 no snakes were detected in the 29 censuses. This alarming reduction in the number of snakes was statistically significant ($\chi^2 = 18.45$, $P = 0.00001$) and indicates that the population of *N. maura* has practically disappeared from the rice fields. The only snakes recorded in 2008 were in the rice fields and canals close to the natural lagoons (25% of the censuses). Likewise, the abundance of green frogs also declined from censuses of 1995 (79% of censuses) to those of 2008 (38% of censuses; $\chi^2 = 10.24$, $P = 0.001$; Table 1). Frog counts also fell in rice fields close to the natural lagoons. In contrast, the presence of fish was greater in 2008, especially in rice fields and canals next to the lagoons (Table 1).

Table 1. Number and percentage of censuses with presence of viperine snakes, green frogs and fish seen in the censuses done in rice fields at the Ebro Delta in 1995 and 2008. In 2008, results were separately presented in censuses made near and far from the natural wetlands.

		Presence (%)		
	Censuses	*N. maura*	*Pelophylax perezi*	Fish
Rice fields in 1995	29	14 (48%)	23 (79%)	2 (7%)
Rice fields in 2008	29	0 (0%)	11 (38%)	6 (21%)
Rice fields in 2008 near wetlands	20	5 (25%)	9 (45%)	12 (60%)

DISCUSSION

This study reports the first evidence that *N. maura* was declining in the Ebro Delta. In fact, the results of censuses in 2008 indicate that the species is near extinction in the rice fields and canals. However, on the basis of our results made near to the lagoons and natural vegetation, we suspect that these habitats serve as refuges for the species, and probably focus of dispersion for snakes to other Delta areas. Although the home range of *N. maura* in the Ebro Delta is not extensive (1.77 ha, Santos and Llorente, 1997), snakes can be transported passively by floating on the water of canals, covering great distances in a single day (more than 500 meters, unpublished data of authors). This species can colonize easily new artificial aquatic habitats (Rugiero et al., 2000; Pleguezuelos and Feriche, 2003; Santos, 2004).

The *N. maura* decrease could be attributed to the reduced availability of one of its main prey, the green frog *Pelophylax perezi*. The consumption of green frogs is vital for female *N. maura* to acquire fat reserves (Santos and Llorente, 2004), and its reduction in the Ebro Delta may affect the snake reproductive output. However, *N. maura* is a generalist and opportunistic predator that often consumes alloctonous fish (Gutiérrez-Estrado and Bravo, 1997; Santos and Llorente, 1998; Rugiero et al., 2000; Santos, 2004). Taking into account the dietary plasticity of snakes with habitat alteration (Luiselli, 2006; Capizzi et al., 2008), we would not expect *N. maura* to be susceptible to extinction by green frog rarefaction. It is well possible that both frogs and snakes in the Ebro Delta declined for some unknown perturbation in the environment. In fact, both species have aquatic habits and therefore the impairment or disturbance of its water habitat could be key factors in their declining (Doré, 1989; Lizana and Barbadillo, 1997; Naulleau and Schätti, 1997; Santos et al., 2002; Santos, 2004). Thus, other causes that can contribute to the reduction of the snake population can be summarized as follows:

1) Bioaccumulation of organochlorine pollutants. The Ebro Delta ecosystem incorporates great amounts of products derived from the agricultural activity in the Delta itself and the industrial activity performed along the river (Pastor et al., 2004; Piqué et al., 2006). In addition to the use of pesticides during rice culture (fungicides, algaecides and herbicides), there is a massive and diffuse use of pesticides for weed control (Mañosa et al., 2001). As predators, snakes accumulate large amounts of chemicals without physi-

ological mechanisms to destroy and remove them (Bauerle et al., 1975; Stafford et al., 1976). In the Ebro Delta, high concentrations of organochlorine pollutants have been reported in *N. maura* muscle (Santos et al., 1999). Viperine snakes accumulate pesticides in such a way that larger individuals have a greater load than smaller ones (Santos et al., 1999). Given the massive use of chemicals in the Ebro Delta and their high persistence, together with the incapacity of snakes to remove these substances from their bodies, we deduce that these chemicals can have a negative effect on its reproduction as observed in other organisms of the Delta (Mañosa et al., 2001).

2) Loss of habitat. There is a progressive transformation of irrigation canals to cement ducts to reduce the loss of water during its transport to the rice fields. In addition, vegetation along the banks of canals is removed by means of herbicides, which are applied for weed control.
3) Mechanical arrangement of canals and rice fields. The harvest of natural vegetation along canal margins, which provide refuge to snakes against predators, accidentally kills many snakes (authors, personal observation).
4) Predation. Among other prey, several herons (e.g., *Bubulcus ibis*, *Nycticorax nycticorax*, *Ardea purpurea* and *Egretta garzetta*) in the Ebro Delta forage on viperine snakes (Ruiz, 1985; Martinez et al., 1992; González-Martín et al., 1992; González-Martín and González-Solís, 1990). Heron populations have risen dramatically since 1986 until now (Fig. 1). Consequently, the predation pressure on snakes and their prey (frogs and fish) has increased, although this has not been corroborated due to the lack of comparative dietary studies of heron populations.
5) Road mortality. Water snakes are commonly found dead on Delta roads (X. Santos, pers. obs.).

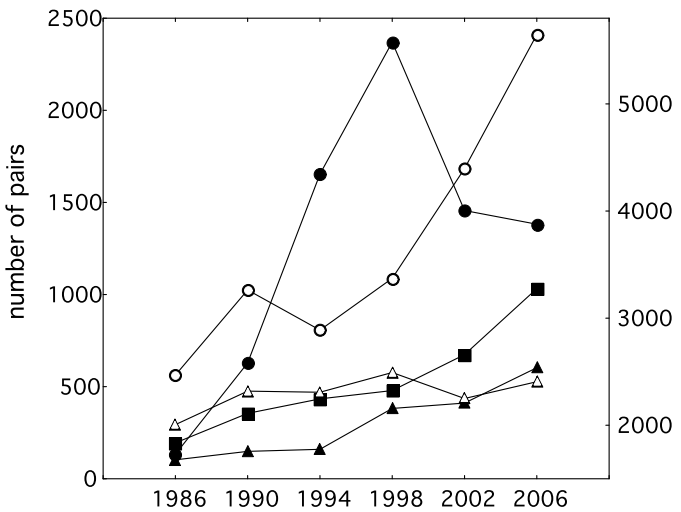

Fig. 1. Temporal variation of reproductive pairs of Heron species in the Ebro Delta. Left Y axis: *Nycticorax nycticorax* (solid triangles), *Ardea purpurea* (empty triangles), *Ardeola ralloides* (solid squares) and *Egretta garzetta* (empty circles). Right Y axis: *Bubulcus ibis* (solid circles). Source: Ebro Delta Natural Park.

6) Direct mortality by people. Some people show great antipathy to these inoffensive animals and sometimes kill them during manual work in the rice fields. In the Iberian Peninsula, local people kill very large female water snakes especially in snake populations with high densities (Hailey and Davies, 1987b).

In summary, here we have measured the reduction of the *N. maura* population in the Ebro Delta. Diverse factors have contributed to this dramatic decline. Some of these directly affect the snake population while others do so indirectly by reducing prey availability or diminishing habitat quality. In order to recover the snake population, extensive changes to habitat management policies are required. During a meeting about the conservation of coastal Mediterranean areas twenty seven years ago, Ruiz et al. (1981) opined that the Ebro Delta, in spite of the high presence of humans, had the capacity to maintain a high animal diversity. Unfortunately, the impact of human activities still is affecting wildlife quality.

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