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Short Communication

Rapid response of a long-lived species to improved water and grazing management: The case of the European pond turtle (*Emys orbicularis*) in the Camargue, France

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ABSTRACT

Among human activities, the effect of habitat management by grazing on population viability is ambiguous. Indeed, beneficial effects of grazing are expected by maintaining open meadows, but overgrazing is supposed to increase mortality by trampling. Grazing has been shown to negatively impact the survival of European pond turtle (*Emys orbicularis*) in the Camargue. Consequently, a new management plan was defined. We investigated the consequences of this management using capture–recapture methods to estimate variations of population sizes in this managed site and a control site over a 17 years period. Results show an increase of the number of adults and juveniles on the managed site after the management change. Our results suggest that improved water management with flooding in autumn provided better hibernation conditions, and that reduced grazing intensity in autumn/winter likely decreased the risk of trampling. Population size significantly increased in less than 4 years following the management change, probably by the relaxation of density-dependence. It is an original result for a long lived-species supposed to have an important time of resilience to perturbations.

Introduction

One third of the reptiles inhabiting marine and freshwater environments are threatened of extinction (Böhm et al., 2013). Higher level of threats to freshwater and marine habitats compared with terrestrial ones are likely responsible for this figure. In particular, 46–57% of the freshwater turtle species are threatened by habitat degradation (Böhm et al., 2013; World Commission on Dams, 2000). Many of these species are particularly affected by home range reduction due to the loss of favourable habitats, competition with invasive species and landscape fragmentation (Williams & Osentoski, 2007).

The European pond turtle (*Emys orbicularis*) is the reptile which has shown the most important range reduction in Europe (>2%) between 1970 and 1990 with increasing fragmentation of populations and the extinction of several relict populations in Eastern Europe (Servan, 1999). Poaching (especially capture with fishtraps), road mortality, invasive species, habitat loss and transformation (Rogner, 2009) are the main causes of this negative trend. In particular, drainage, channel constructions, water regulation and dike management generally cause strong habitat homogenization and population fragmentation (Rogner, 2009). Furthermore, the conversion of wetlands to croplands generates additional threats for European pond turtles by exposing them to water pollution.

European pond turtles require both good quality freshwater habitat for foraging and terrestrial habitat with open areas and low plant cover for successful nesting (Ficetola et al., 2004). In this context, cattle grazing may provide open meadows offering favourable nesting sites, essential for the breeding dynamics of the species as was shown in the bog turtle *Glyptemys muhlenbergii* (Tesauro & Ehrenfeld, 2007). However, the benefits of grazing remain controversial: some authors argue that intensive grazing negatively affects the survival of herpeto-fauna by changing the macrohabitat (vegetation structure) or microhabitat (ground temperature),

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decreasing prey abundances (Wilgers et al., 2006), or increasing the numbers of injured animals by trampling (Olivier et al., 2010).

Olivier et al. (2010) compared the dynamics of two European pond turtle populations of the Camargue (south of France) facing different managements, the Esquineau population face intense grazing and a variable water management while the Faïsses site has constant conditions of management characterized by moderate grazing intensity and stable water levels. The Esquineau population was found to be declining and individuals were found to present shell damaged by cattle trampling. It was thus hypothesized that trampling increased turtle mortality and consequently reduced the numbers of individuals (Fig. 1). In parallel, we suspected that natural winter flooding was too late to offer optimal hibernation conditions since overwintering starts as soon as autumn (Rogner, 2009). Therefore, sites offering better conditions for hibernation due to the dense vegetation (that allows stable conditions to be maintained during the winter; Thienpont et al., 2004) were unavailable, forcing European pond turtles to take refuge in areas less favourable, which may have increased mortality during the hibernation period. Based on these hypotheses, in 2007, a new management plan was implemented at the Esquineau so that flooding started in autumn and the timing and stocking rates of cattle were changed with moderate grazing intensity outside the active period of turtles (Fig. 1). In an adaptive management perspective, monitoring the change of turtle population size following this management change should allow evaluating the effect of grazing and water management on this species. Adaptive management is a conservation strategy that aims to "learn by experimenting" (McLain & Lee, 1996; Walters, 1986). The principle is to establish a management policy based on assumptions and models of the functioning of the system, and to assess their effectiveness *a posteriori* (Berkes et al., 2000; Maris & Béchet, 2010). Hence, 7 years after management change we evaluated the effectiveness of the conservation measure taken to prevent the decrease of the *E. orbicularis* population to validate the hypotheses made on the functioning of the system. In particular, we expected that mitigating the grazing pressure and changing water management would allow population size to return to the first period state.

Materials and methods

Study area and sampling

The two populations of *E. orbicularis* studied are located in the natural reserve of the Tour du Valat in the Camargue (southern France, ~43°30′N, 4°40′E). The first site, the Esquineau, has a total area of 250 ha. The second site, the Faïsses (Moncanard in Olivier et al., 2010) covers a surface area of 100 ha. The studied populations are ~1.5 km apart. At both sites European pond turtles inhabit two kinds of habitats: permanent and semi-permanent marshes managed by man-made irrigation (the majority of the Esquineau) and drainage canals with presence of water all years round (the majority of the Faïsses; Olivier et al., 2010).

From 1997 to 2013, turtles of both populations were captured from April to August with fishtraps and by hand with the same methodology as Olivier et al. (2010). For each capture, the age, sex and shell condition (damaged or not) were recorded. Sex was identified by observing male secondary sexual characteristics: concave breastplate, orange eyes (yellow in females), basic wide tail and cloacae away from the plastron (Zuffi & Gariboldi, 1995). Turtles were classified as adults if they had no visible growth rings (Castanet, 1988). In juveniles, reading these growth rings allows to determine the individual birth year (Olivier, 2002). The juvenile term represents individuals from second year life to maturity phase. The individuals in their first year life are called emergent. Each individual was marked (except emergent) with permanent notches cut into the carapace marginal scutes with a small hacksaw (Cagle, 1939). Turtles were returned within 24 h to the place where they had been collected. A total of 7059 captures corresponding to 963 different individuals was obtained over the 17-years study period. More precisely, the dataset includes 364 adults and 276 juveniles from the Esquineau and 207 adults and 116 juveniles from the Faïsses. For adult individuals, data from Olivier et al. (2010) were used from 1997 to 2006 and new data were supplemented from 2007 to 2013. A new dataset was used for juvenile individuals.

Both horses and cows graze on land and in the marshes. Grazing intensity was calculated as P = (*number of adult livestock* * *number of months of grazing*)/(*grazed area (ha)*). We arbitrarily defined 3 thresholds of grazing intensity: low under a value of 2, high above of 5 and moderate between these two values. The duration of grazing periods varies between years: 1) all year long between 1997 and 2001; 2) in spring and summer between 2002 and 2006; 3) in autumn and winter after 2007 (Fig. 1).

Water levels were measured 2 to 3 times per month and dry period were recorded. Before 2002, water was present in marshes and canals all year long. Since 2002, water levels were modified with a dry period at the end of summer and a natural flooding by rainfall in winter. After 2006, flooding was artificially supplemented by pumping in autumn. Both management changes only affected the Esquineau site so that the Faïsses site can be considered as a control site.

Statistical analysis

We estimated annual variations of the European pond turtle population size at each site separately for each age-class (adult and juvenile) by using close population models. Each year from two to five sampling periods were performed. These sampling periods were used to build the capture histories. Each sampling period length between three to five days was then pooled in our analysis. We first tested for each year whether the population was closed or not by using CLOSE-TEST (Stanley & Burnham, 1999). Then we estimated population size at each of the 17 years with the CAPTURE module (Rexstad & Burnham, 1991) of MARK software (White & Burnham, 1999). CAPTURE allows varying assumptions regarding capture probabilities including: i) inter-individual heterogeneity of capture (M*h*); ii) time variation in capture probability (M*t*); iii) a behavioural response to the first capture (M*b*) and the different possible combinations of effects on capture probabilities. The best model is selected based on the maximum value (between 0 and 1) of a discriminate model selection criteria specific to CAPTURE. We calculated the size of the whole population by adding the number of adults and juveniles estimated each year for each population.

We attempted to explain annual population size variations at the two sites by using Generalized Linear Models (GLM) with a Gaussian distribution for the error term. We included the standard error of the population size as weight to take into account inter-annual variations in the precision of the estimate. We evaluated the fit of models by checking normality, independence and homoscedasticity of residuals. We first tested for a difference of population size between sites. Then we tested for each population the effect of age (juvenile or adult), and of the three periods corresponding to the three management plans: a single period 1997–2013, two periods 1997–2001/2002–2013 and 1997–2006/2007–2013, and three periods 1997–2001/2002–2006/2007–2013. Model selection was achieved using the Akaike Information Criterion corrected for small sample size (AICc; Burnham & Anderson, 2002). Model with the lower AICc value is considered as the best model for the data at hand. Models with an AICc difference less than 2 are considered

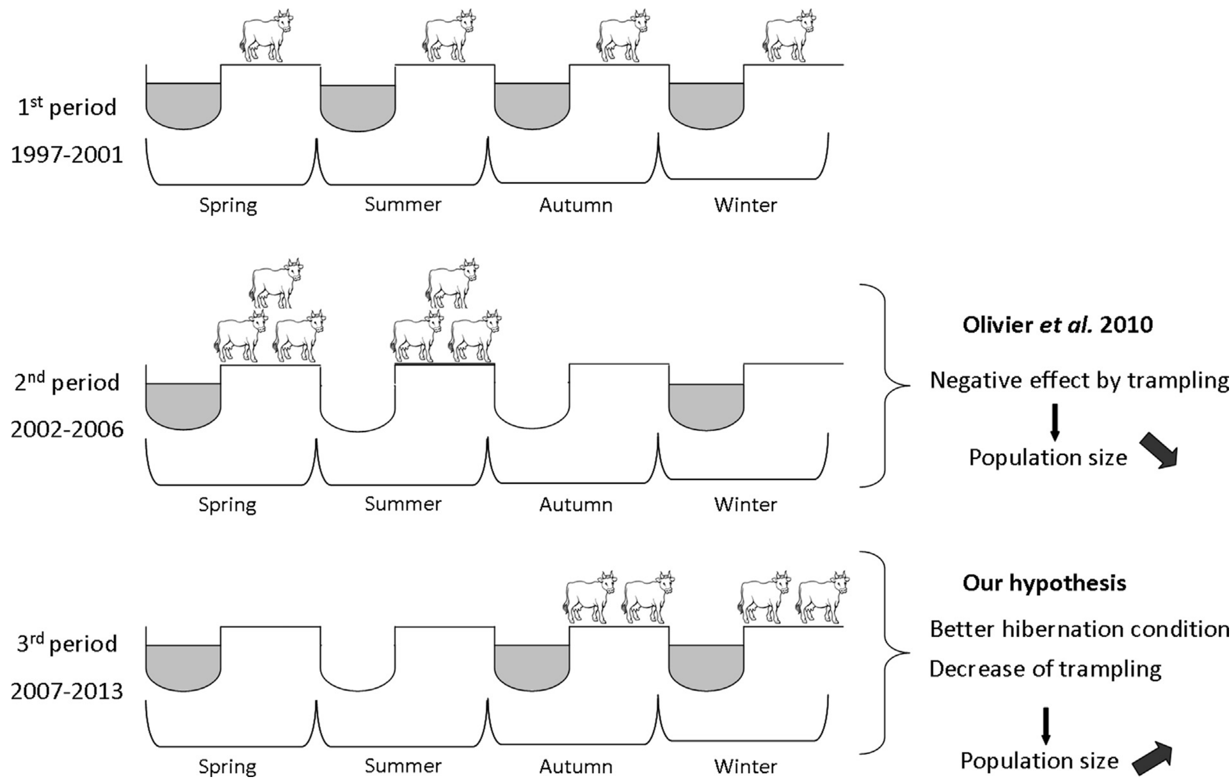

Fig. 1. Characteristics of the different management plans at the Esquineau European pond turtle population (Tour du Valat) from 1997 to 2013. The number of cows reflects cattle grazing intensity: low (one), moderate (two) and high (three). Areas in grey show the presence of water and blank areas its absence. Flooding of marshes in autumn was artificial and in winter was natural.

as equivalent to describe the data. GLM were implemented in R version 2.7.2 (R Development Core Team, 2008)

Results

At the Esquineau, grazing intensity was stable and low between 1997 and 2001. In 2002, the livestock density was multiplied by 2.5 and the grazing intensity was high. Since 2007, the grazing intensity has been more fluctuating and can be considered as moderate (Fig. 1). At the Faïsses, grazing intensity has remained moderate from 1997 to 2013.

For both sites, we noted 3 phases of recruitment (Fig. 2) determined from the increase of number of newly marked individuals to a peak. At the Faïsses, the recruitment occurred between 1998 and 2000, between 2002 and 2003 and between 2005 and 2007 with a peak at 7, 8 and 10 individuals, respectively. At the Esquineau, we observed the recruitment between 1996 and 1998 with a peak at 15 individuals, between 2004 and 2007 with peak at 26 individuals and between 2008 and 2009 with a peak at 14 individuals.

Damaged shells were noted on 32 individuals mostly on adult females and male juveniles at the Esquineau (9 and 7, respectively; Table 1). Trampling seems to be more important between 1997 and 2001 and between 2007 and 2012 than between 2002 and 2006 (15, 12 and 5, respectively; Table 1).

Close tests indicated that the closure assumption within primary periods was supported in ~70% of years. Among the top six models receiving the highest scores based on the CAPTURE algorithm for model selection, model with time-variation in capture probability (M*t*) was selected for adult data sets. For juvenile data sets, models without effects (M_0) and with heterogeneity at the capture (M*h*) were selected for the Esquineau and the Faïsses, respectively.

The Faïsses and the Esquineau populations appear to fluctuate independently of one another over the study period (Table 2, M1 *vs* M2, ΔAICc = 22.4) supporting effects of different managements plan at the Esquineau.

The Faïsses population does not show any consistent size variations when different management plans were applied to the Esquineau site (Table 2, M10 *vs* M11, ΔAICc = 4.1) so that this population appears relatively stable with 73 ± 21 individuals (Fig. 3c). Results suggest that the Faïsses show a strong age effect but independent of any of the management plans (Table 2, M9 *vs* M14, M15 ΔAICc ≥ 4.4).

Contrary to the Faïsses, the Esquineau population size varies depending on the three management plans (Table 2, M5 *vs* M6, M7 and M8, ΔAICc ≥ 7.7; Fig. 3c). Model selection supports the hypothesis that variations of population size are age-dependent (Table 2, M3 *vs* M4, ΔAICc = 2.4). Adult population size was 206 ± 19 individuals during the first period, decreased to 145 ± 30 between 2002 and 2006 and increased to 300 ± 90 during the last period (Fig. 3a). The juvenile population follows similar variations with a greater magnitude (Fig. 3b). Population size dropped from 43 ± 30 to 15 ± 9 between the first and the second period, a decline of 65% compared to adult population which decreased of only 30% over the same period. After 2006, the average population size of juveniles increased by 700% reaching 120 ± 50 individuals, while this rise was only 107% for adults. The increase of the juvenile population size seems to start in 2006 (Fig. 3b), two years before the increase observed in the adult population (Fig. 3a).

Discussion

In an adaptive management approach, our study aimed at evaluating the effect of two management measures taken to restore European Pond turtle populations in the Camargue. In particular, we hypothesized that high grazing intensity and late flooding

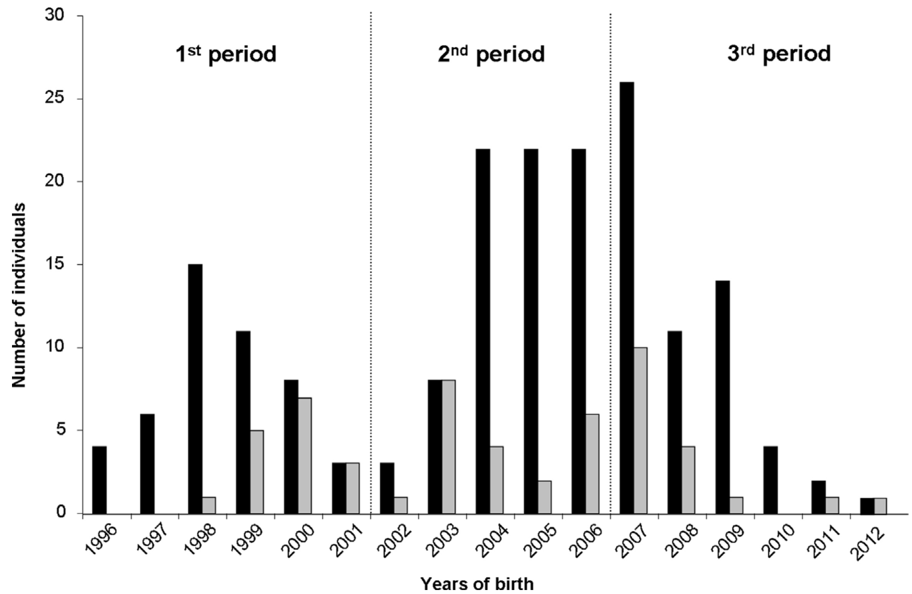

Fig. 2. Number of European pond turtle births per year as estimated from the age of the newly marked individuals of *Emys orbicularis* captured at the Tour du Valat for each study site (the Esquineau in dark and the Faïsses in grey) for the three different management plans.

Table 1
Number of *Emys orbicularis* individuals found with severely damaged shell by management plan, site, sex and age at the two study populations Esquineau and Faïsse in the Camargue.

	Female Esquineau	Male Esquineau	Female Faïsses	Male Faïsses	Total Esquineau/Faïsses
Adult					
1997–2001	6	3	0	1	9/1
2002–2006	2	0	0	1	2/1
2007–2013	1	3	2	0	4/2
Juvenile					
1997–2001	2	2	1	0	4/1
2002–2006	1	1	0	0	2/0
2007–2013	2	4	0	0	6/0

management could be two factors that negatively impact European pond turtles.

Our results suggest distinct situations between sites in the variations of population size. At the Faïsses, the control site where management remained the same throughout the study period, the whole population slightly fluctuates between 1997 and 2013. At the Esquineau, the managed site, the population sizes vary following the changes of management plans. Even if the respective effects of

Table 2
Generalized Linear Models to evaluate a) the effect of site on population size; b) the effect of age and of the different management plans on annual population sizes at the Esquineau (b) and the Faïsses (c). *pop*: Esquineau, Faïsses; 1: first period (1997–2001); 2: second period (2002–2006); 3: third period (2007–2013); Δ: difference of AICc between models and the first model (M1, M3 and M9, respectively). K: number of parameters; Ω: Weight of each AICc in the global analysis; R^2: coefficient of determination; * effect with interaction between qualitative variables; + effect without interaction.

No.	Model	Deviance	AICc	Δ	K	Ω	R2
a)							
M1	*(1/2/3)*Pop*	1093.6	737.6	0	7	1.00	0.38
M2	*(1/2/3)+Pop*	1643.2	760.0	22.4	5	0.00	0.06
b)							
M3	(1/2/3)*Age	50.25	322.9	0	7	0.60	0.96
M4	(1/2/3)+Age	64.52	325.3	2.4	5	0.40	0.95
M5	(1/2/3)	604.3	398.6	75.7	4	0.00	0.52
M6	1–2/3	817.89	406.3	83.4	3	0.00	0.35
M7	1/2–3	1054.9	414.9	92	3	0.00	0.16
M8	1997–2013	1249.6	418.3	95.4	2	0.00	0.68
c)							
M9	Age	130.33	302.2	0	3	0.489	0.74
M14	(1/2/C3	155.33	306.6	4.4	5	0.260	0.69
M15	(1/2/3)*Age	130.33	307.1	4.9	7	0.242	0.74
M10	1997–2013	504.06	337.6	35.4	2	0.003	0.35
M13	1/2–3	492.90	339.3	37.1	3	0.002	0.02
M12	1–2/3	503.15	340.0	37.8	3	0.002	0.00
M11	(1/2/3)	489.27	341.7	39.5	4	0.002	0.03

grazing and water management cannot be disentangled, our results suggest beneficial effects of these two factors.

The availability of water is essential for the survival of European pond turtle (Rogner, 2009). *Emys orbicularis* uses wetlands for feeding, mating and hibernating. In the Camargue, marshes are dry by the end of summer. The natural flooding of marshes may occur at the end of autumn or in the beginning of winter. But flooded marshes constitute favourable sites to hibernate that European pond turtles seek as early as October (Olivier, 2002). Therefore, in natural conditions, marshes would most often been dry when turtles start hibernation, so that they are constrained to hibernate in channels where thermal conditions are supposed less stable due to the lack of dense vegetation and more variable water levels (Thienpont et al., 2004). By artificially flooding marshes in autumn we expected that turtles would get better hibernation conditions, thus promoting higher winter survival. Increased population sizes after this change suggest that this measure positively affected population size.

The number of trampled turtles by management plan and per site is insufficient to detect an evolution of damaged shells and the individual mortality, here not detected, caused by the changes of management. In addition, the low overlap between grazing periods and the European pond turtle availability to trampling inevitably leads to a decreased risk of being crushed. Furthermore, the evaluation of the trampling impact on *Emys Orbicularis* is difficult to measure. Indeed, some turtles are not caught over several years. Consequently it is impossible to know the period during witch the turtle was trampled. Therefore the probability to catch more

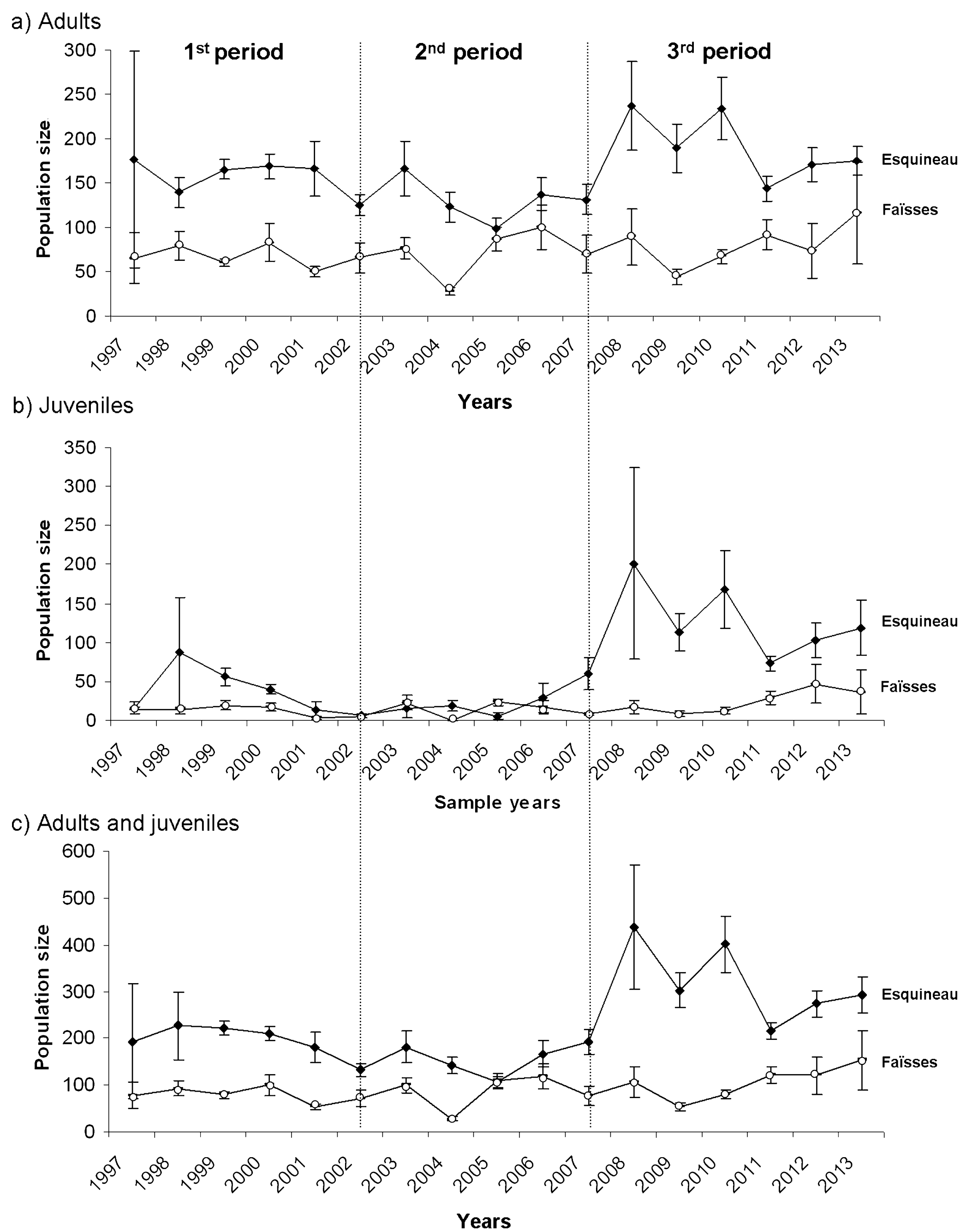

Fig. 3. Population size (± SE) of *Emys orbicularis* at Tour du Valat, for the three different management plans. (a) For adults. (b) For juveniles (c) For the whole populations. Black square curve are for the Esquineau and open circle one for the Faïsses site (the control site).

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trampled turtle over the years increases. However, data suggest that the trampling of turtles by livestock remain significant on our study sites and in a short term, high grazing intensity can negatively affect turtles. In *Mauremys rivulata*, overgrazing causes heavy disturbance by trampling, suggested to be a factor of juvenile and adult mortality. It can also have negative consequences on the reproductive biology, with a possible disruption of nesting areas (Chelazzi et al., 2007). In European pond turtles, trampling, which occurs during the movements of individuals (dispersal for males, and terrestrial nesting for females), likely increased mortality on adults and therefore contributed to decrease the numbers of individuals between 2002 and 2006 (Olivier et al., 2010). Nevertheless, European pond turtle at the Tour du Valat do not seem to be severely affected by the relatively high grazing intensity implemented in autumn and in winter during the last management plan since even if the grazing intensity was high, the impact on turtles remained low because individuals are inactive during hibernation (Rogner, 2009) and protected from trampling by mud (*i.e.* the earth soil layer). In the case of *Emys orbicularis*, grazing prevents the closure of terrestrial habitat and maintains favourable nesting sites.

Our results also emphasize that the rapidity of the response of this long-lived species to the change of management. Indeed, European pond turtles are long-lived animals with a late age of first reproduction (Rogner, 2009). Consequently, the generation time is very high and the time of resilience to perturbations is also expected to be high (Couturier et al., 2011; Pitt & Nickerson, 2013). Our results contrast with this prediction. Yet they are similar to the observations made by Cheylan and Poitevin (1998) who studied the impact of fire on population of *Emys orbicularis* in the Massif des Maures (Southern France). They showed that despite the decrease of abundance and mortality of individuals after a fire, the population could be restored in only 5 years by high recruitment.

The relaxation of density-dependence may explain the low time of resilience to perturbation observed in our populations (Vincenzi et al., 2010). Indeed, as population size dropped during the second plan, the decrease of intraspecific competition may have facilitated an important and rapid recruitment of the newly born individuals from 2004 (Fordham et al., 2009; Fig. 2) despite a low and stable fecundity across years (5 adults per 1000 eggs laid on average; Olivier, 2002). This recruitment can result from an increase of the numbers of juveniles newly marked from 2006 (we observed at the Tour du Valat that the juveniles are caught for the first time around 2–3 years). The sudden increase of the number of adults captured from 2008 can be explain by the better water condition that have facilitated an increase in the Esquineau population size by attracting nearby adult turtles from unmanaged marshes of Esquineau (in particular those located in an adjacent private property). The recruitment of both age categories intensifies with the third management plan. In contrast the decrease of the number of newly marked individuals after 2008 (<5 individuals in recent years) may be explained by the increasing intraspecific competition following population restoration. As the majority of individuals born from this last recruitment have been captured and marked, we predict that in a few years the numbers of juveniles in the whole population will progressively decrease. On the contrary, the population of adults should increase in the next 3 to 5 years.

Our study shows the importance on one hand of the adaptive management of aquatic habitats in an anthropic system, and on the other hand of the long-term monitoring of populations for the conservation of freshwater turtles species.

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