Population modelling to assess supplementation strategies for the European pond terrapin *Emys orbicularis* in Liguria

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Abstract. We present the results of modelling the supplementation program for *Emys orbicularis* in Liguria. We evaluated three possible alternative strategies for the reintroduction, releasing 3-, 4- or 5-year-old turtles. In particular, we wanted to assess the expected population sizes that could be achieved by these release strategies, given environmental and demographic stochasticity, and the possibility that captive-bred individuals, when released, suffer greater mortality than those born in the wild. We built a stage-structured model for a reintroduced population and parameterised it using published and unpublished information. We compared the outcomes of population viability analyses for releases of 3-, 4- or 5-yr old turtles, explicitly accounting for uncertainty in the estimated parameters and investigating the effect of an increased mortality in the year after release.

Assuming post-release effects would affect all life stages equally, releasing 5-yr old turtles was always the most effective option, with the highest predicted number of mature individuals in the wild population after 20 and 50 years. However, releasing 3- and 4-yr-old turtles was also predicted to provide positive results, and may prove a cheaper strategy since it requires a smaller captive population. In the event that post-release survival has a greater impact on older individuals, their release may become less advantageous and even sub-optimal. Therefore, future monitoring and analysis should concentrate on resolving the uncertainty for this parameter, since it is the most likely to affect management decisions and outcomes.

Riassunto. In questo studio vengono presentati i risultati di un modello di popolazione per il programma di rinforzo delle popolazioni di *Emys orbicularis* in Liguria. Usando un modello di popolazione, vengono valutate tre possibili strategie di rilascio (individui di tre, quattro o cinque anni di età): in particolare, le proiezioni della dimensione totale di una popolazione che risulterebbe da ciascuna strategia di rilascio, considerando incertezza e processi stocastici, oltre alla possibilità di una diminuzione nella sopravvivenza post-rilascio degli individui allevati in cattività.

Usando un modello a classi d'età, con parametri derivati da letteratura esistente e dati non pubblicati, vengono confrontati i risultati proiettati da un'analisi di viabilità (PVA) per una popolazione reintrodotta, incorporando gli effetti dell'incertezza nei parametri chiave e la possibile mortalità aggiuntiva nel primo anno dopo il rilascio. Se l'effetto di tale mortalità rimane costante per ogni classe di età, il rilascio di individui di cinque anni risulta l'opzione più efficace, massimizzando il numero di individui nella popolazione reintrodotta dopo 20 e 50 anni. Tuttavia, il rilascio di individui di 3-4 anni di età appare sufficientemente efficace e può consentire di contenere i costi di gestione, richiedendo meno tempo in cattività per individuo. Nel caso in cui la diminuzione nella sopravvivenza post-rilascio risulti più consistente per individui più anziani, il rilascio di questi ultimi può divenire meno vantaggioso e anzi controproducente. Pertanto, futuri piani di monitoraggio e analisi dovrebbero incentrarsi sulla sopravvivenza degli individui liberati, poiché questo parametro appare quello maggiormente in grado di influenzare le decisioni di gestione e i loro risultati.

Keywords. Captive breeding, population viability analysis, turtle, uncertainty.

Introduction

The European pond terrapin *Emys orbicularis* was considered to have been extirpated from Liguria until the re-discovery of small, isolated populations in the Albenga plain. Within a species recovery project coordinated by the Savona Provincial Administration, a captive breeding centre was set up in 2000. The captive breeding program has been increasingly successful over the years, and the centre is now producing a significant number (about 60 juveniles each year) of individuals for release into the wild. As part of the LIFE EMYS project (LIFE12 NAT/IT/000395), a full-scale program of releases will be implemented in the next three years. The choice of an adequate release strategy is particularly important given the limited time and resources available and the uncertainty surrounding population dynamics of the species.

The focus of this study was to identify the optimal strategy for release using a population model for the species. We built and parameterised the model using published and unpublished information; we projected the size of the wild population in 20 and 50 years after the releases, accounting for environmental and demographic stochasticity, and comparing different release strategies (releasing individuals of three, four or five years of age). Finally, we assessed how the outcomes of the reintroduction might be affected if captive individuals had greater mortality than wild individuals after their release.

Methods

We modelled a reintroduced population of *E. orbicularis* using a stage-structured model. We defined eight stages, modelling only females (Figure 1): stages 1-6 correspond to 1-yr increments in age, from hatchlings to 6-yr olds; stage seven includes turtles between 7-11 years old (young mature females: D. Ottonello, *pers. obs.*), with an age-dependent increase in fecundity; stage eight included turtles older than 12 years, which have reached a constant fecundity rate (D. Ottonello, *pers. obs.*). We parameterised the model based on published and unpublished literature. For every parameter we defined mean and standard deviation (the latter reflecting environmental stochasticity). We derived the survival rates of each stage directly from previous studies (Table 1).

We calculated annual fecundity as the result of a number of factors:

1. The probability that a female breeds in a given year.
2. The clutch size, increasing with age; we calculated this by fitting a Von Bertalanffy growth function to a database of 76 body sizes from three populations in Liguria and Toscana, and relating the estimated age of individuals to clutch sizes for the same individuals. The model assumed that clutch size remained constant for individuals older than 12 years.
3. The probability of laying a second clutch; based on observations for the Ligurian population, we set the probability of laying a second clutch to 0.5 for turtles between 7 and 11 years of age, and to 0.8 for turtles older than 12 years.
4. The size of the second clutch, assumed at 60% of the first clutch.
5. The probability that a nest is not destroyed by predators.
6. The probability that a surviving egg hatches.

Table 1. Vital rates for stage-structured model for *Emys orbicularis*. Values for each parameter indicate mean and standard deviation (used to determine environmental stochasticity). Uncertainty indicates the parameters used to define a probability (beta) distribution for the respective parameters, and inputed in the sensitivity analysis.

	Parameter		
Stage	Survival	Fecundity	Uncertainty of mean (min – mode – max)
Hatchlings	0.08±0.03 [1]	0	0.02 – 0.08 – 0.2
1-yr-old	0.53±0.03 [2]	0	-
2-yr-old	0.8±0.14 [2,3]	0	-
3-, 4-, 5-yr-old	0.9±0.01 [3, 4]	0	0.45 – 0.9 – 0.99
6-yr-old	0.9±0.01 [3, 4]	0	-
7-11 yr-old	0.96±0.01 [3,4,5]	0.64±0.15	0.55 – 0.64 – 1.15
12+ yr-old	0.96±0.01 [3,4,5]	1.11±0.43	0.68 – 1.11 – 1.69

[1]: Paul 2004; [2]: Mitrus 2005; [3]: Mitrus and Zemanek, 2004; [4]: Zuffi, *unpubl. data*; [5]: Cordero and Fernandez 2001.

The studies we used to estimate vital rates for *E. orbicularis* are the best currently available data for our purpose; however, they encompass several subspecies over a large geographical area, often with considerable differences in vital parameters. Therefore, we integrated a full sensitivity analysis in the simulation. We identified four key uncertain parameters: the survival of nests, the survival of hatchlings and of 3-, 4- and 5-yr-olds, and the probability of laying a second clutch for mature females. For each of those, we defined a maximum, minimum and most likely value, reflecting the estimated similarity of each study reviewed to the Ligurian population (Figure 1; Table 1). For example, we expected the vital rates of the Ligurian subspecies to be closer to those in central Italy than in Poland. We then used these values to define a beta-PERT distribution for each uncertain parameter.

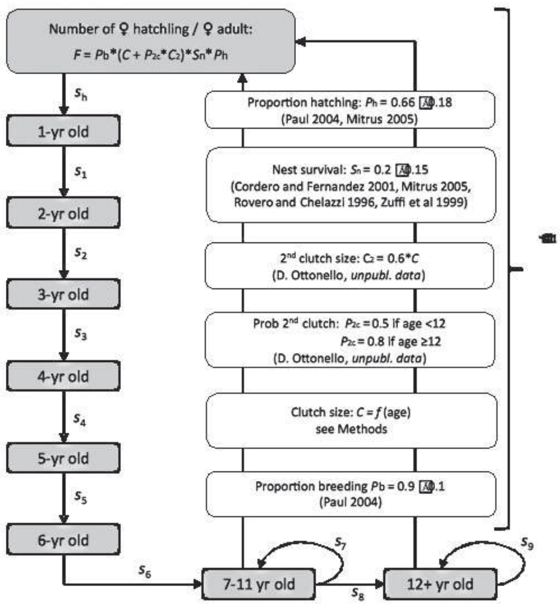

Fig. 1. Stage-structured model for *E. orbicularis*. Filled boxes represent the life stages modelled. Labels s_i indicate the survival rates of individuals. Empty boxes indicate the components of the fecundity process, with the source references for the parameterisation.

To obtain predictions of population dynamics under different management scenarios, we simulated the annual release of 20-30 females for three years and evaluated the resulting number of mature individuals in the wild population after 20 and 50 years. We assumed the initial wild population consisted of ten individuals in the mature (12+) stage, reflecting its small current size. We modelled environmental stochasticity using the defined means and standard deviations for log-normal (fecundity) and beta distributions (survival), and demographic stochasticity using binomial and Poisson distributions for survival and fecundity respectively. We allowed exponential growth, assuming the population would remain under the current carrying capacity *K* at the reintroduction site for the limited time frame of the release program. We then assessed the effect of post-release mortality in released individuals. We repeated the simulation changing the survival of the released stage as a proportion (from 0.5 to 1) of the corresponding survival in the original matrix.

Results

Releasing older individuals was generally more effective, although stochasticity and uncertainty determined considerable overlap among all three strategies, and releasing younger individuals still led to large population sizes (Figure 2). These outcomes were sensitive to a reduction in the survival of individuals in the year after release (Figure 2). The relatively high survival of individuals would partly buffer this effect: predictions suggested that even with a 50% reduction, all strategies still had a high probability of producing a wild population in excess of 100 adults in 50 years. If the reduction in survival were greater for older individuals, then the advantage in releasing 5-yr-olds may be reduced or even negated. For example, if the reduction in survival post-release were 40% for 5-yr-olds, and 20% for 4-yr-olds, the two strategies would be almost equivalent in terms of predicted outcome.

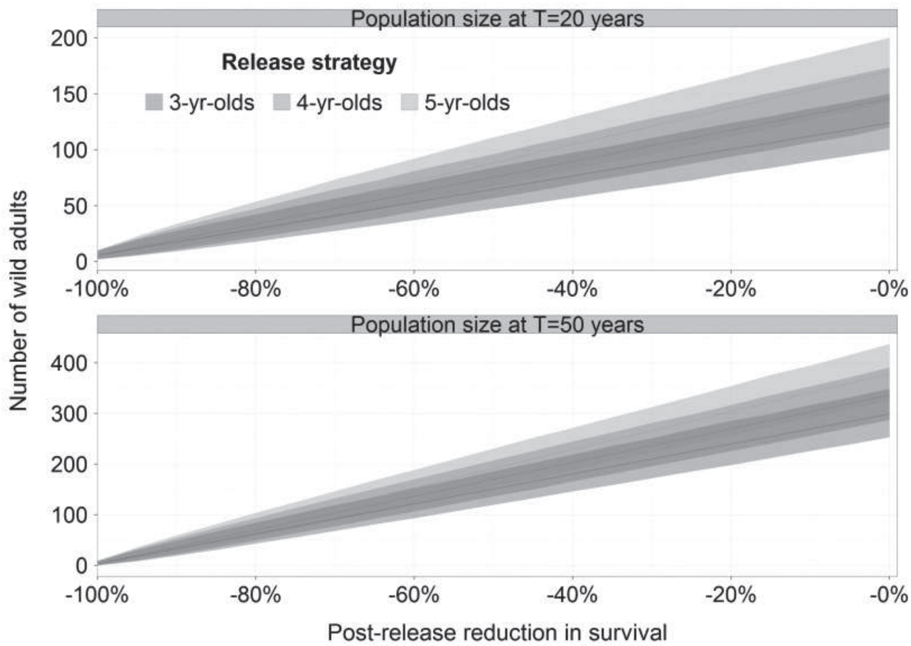

Fig. 2. Outcomes of the simulation and their sensitivity to an increase in the mortality of individuals in the first year after release. The shaded area indicates 95% confidence intervals across 1,000 simulation runs, including uncertainty in the key parameters.

Discussion

As expected, releasing older individuals increases their probabilities of reaching maturity, bypassing juvenile stages with higher mortality. Therefore, a decision based purely on the average expected size of the wild population would focus on releases of 5-yr-old turtles. However, when accounting for uncertainty and stochasticity there was considerable overlap between all strategies. Since the difference in survival between the candidate stages is limited, releases focusing on younger individuals were also predicted to provide positive results. This should be taken into account when evaluating other factors: for example, releasing older individuals implies they will be maintained in captivity for longer, leading to a larger captive population and potentially increasing costs. This could generate a trade-off and lead to different considerations. For example, a decision to release 4-yr-old individuals could aim to reduce the costs of the captive population, accepting a marginally lower outcome, and diverting the resources saved to other activities (such as improved in-situ management or education).

A key aspect of this trade-off is the potential effect of captivity on individuals. Although the survival of older individuals is higher, it is possible that by spending more time in captivity they incur additional impacts upon release. Although this was modelled as mortality, adult individuals may also be more likely to disperse from the release site, or they may have reduced fertility. The existence of such release effects has been observed in several reintroductions: future research should focus on this parameter.

Finally, our results reflect several assumptions. Density dependence may influence population dynamics, although its effects would probably be reduced in a species with high survival, low fecundity and long generation times. In general, however, we expect such dynamics to affect the population similarly regardless of release strategies: our focus here was rather on the *relative* differences between releasing 3-, 4- and 5-yr-olds, and further analysis is needed to assess the *absolute* benefits of the supplementation. Perhaps the most important assumption is that in-situ management will be adequate to increase the availability and connectivity of nesting sites, necessary to ensure long-term viability.

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