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Fibrocement slabs as useful tools to monitor juvenile reptiles: a study in a tortoise species

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Abstract. Most species of tortoises are seriously threatened worldwide. Chelonians are long-lived organisms characterized by slow demographic traits; mathematical modeling estimated that a high rate of juvenile annual survival (i.e. >0.6 on average) is essential for the persistence of populations. Unfortunately, current knowledge about free-ranging juveniles is fragmentary. Under field conditions, young tortoises are very secretive, they remain sheltered beneath bushes, and they escape capture. The resulting lack of information impairs the assessment of key parameters such as juvenile survival, habitat use, or recruitment rate and thus seriously impedes both accurate population viability analyses and conservation planning. Large-scale monitoring of different populations of a threatened species (*Testudo hermanni hermanni*) confirmed that juveniles are rarely seen in the field. In 2011, we placed corrugated fibrocement slabs as alternative refuges for small tortoises in a densely vegetated study site. Many juveniles sheltered under the space offered by the corrugations; consequently they were easily captured and recaptured. Our results suggest that this simple technique may significantly improve the detectability of juveniles, providing access to the life history traits of this otherwise elusive age cohort. The slabs also provide protection against predators (such as dogs and birds) which further suggests that these refuges may also improve the survival of the smallest and most vulnerable individuals.

Keywords: artificial refuges, juveniles, population survey, *Testudo hermanni*, tortoise conservation.

Introduction

Populations cannot persist in the absence of reproduction or sufficient juvenile recruitment. Therefore population viability analyses rely heavily on key demographic parameters such as adult survival, fecundity, juvenile survival, recruitment rate and age at maturity. Unfortunately, in most reptile species, at least two of these crucial parameters are often unavailable: juvenile survival and recruitment rate. The major reason for this lack of knowledge is imputable to the extreme secretiveness of the juveniles: mark-recapture data are usually so fragmented that adequate demographic analyses remain unfeasible.

To overcome this difficulty, indirect estimates of juvenile survival have been performed using mathematical modeling based on free-ranging adult females (Pike et al., 2008). The calculations suggested that juvenile survival is more elevated than previously assumed to allow for the persistence of populations. Likely, the very low catchability of juveniles in the wild promoted the incorrect, albeit widespread, notion that juveniles exhibit a markedly lower survival rate compared to conspecific adults (Pike et al., 2008). This assumption formed the basis of conservation efforts to protect adult females and breeding sites, while juveniles were neglected under the (often incorrect) assumption that an abundant production of offspring was sufficient to sustain populations, irrespective of the survival of the juveniles. The results of Pike et al. (2008) therefore rectified this bias. However, their estimates were based on a central assumption: a perfect stability of population size over time. Unfortunately most reptiles show worrying signs of decline worldwide, sometimes manifested through rapid and drastic popula-

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tion collapses (Gibbon et al., 2000; Reading et al., 2010). This negative trend renders the indirect estimated juvenile demographic traits inaccurate (or obsolete) in most populations. Directly monitoring the juvenile age class in the field is consequently a necessity for many reptile species. Novel field techniques may provide an advantage in juvenile captures and therefore a simple means of accessing information about this age cohort.

Among reptiles, terrestrial tortoises are particularly concerned by these problems. Almost all chelonian species are threatened (Gibbon et al., 2000; Buhlmann et al., 2009). Their physiology/anatomy (slow moving animals with limited escape techniques), commercial value (intensive use as food [notably the eggs] or pets) and life history traits (low fecundity, slow growth, late maturity) translate into a strong susceptibility to anthropogenic disturbances. The required average annual survival rate of juveniles for population stability was estimated to more than 0.6 (Pike et al., 2008), a remarkably high value considering the vulnerability of small tortoises. This value fits well with the few estimates available ranging from 0.52 to 0.67 on average in two *Testudo hermanni* populations where adequate numbers of juveniles have been monitored over time (Henry et al., 1999; Fernández-Chacón et al., 2011). In most chelonian population however, juvenile age class remains elusive (Kazmaier et al., 2001; Pike and Grosse, 2006; Pike and Reeder, 2006).

Accurate surveys of free-ranging juveniles are important to assess if the majority of juveniles are actually escaping detection and thus if a high survival rate is a key factor (irrespective of the level of production offspring) calling for an urgent need to better monitor and protect this age cohort.

We tested a simple technique to improve the catchability of juvenile terrestrial tortoises. Our reasoning was straightforward: Juveniles are not engaged in conspicuous reproductive activity whereas foraging activity usually requires little time per day (Stubbs and Swingland, 1985; Lagarde et al., 2003; Pike and Reeder, 2006), and they suffer from high predation pressure especially by widespread feral dogs, feral pigs and beech martens (Stubbs and Swingland, 1985; Coblentz and Baber, 1987; Jolley et al., 2010). As such, in many cases, juvenile tortoises presumably spend considerable amounts of time sheltered, notably under thick vegetation, bushes, logs and stones (Blomberg and Shine, 2004; Pike and Reeder, 2006), thereby escaping human observers. Providing alternative, suitable and easily accessible refuges may attract small tortoises. We set up a network of corrugated fibrocement slabs in the field; a technique routinely used to enhance the catchability of all age classes in snake and lizard surveys (Reading, 1997; Bonnet, Naulleau and Shine, 1999; Hampton, 2007; Thierry et al., 2009; Le Lièvre et al., 2010). However, tortoises lack the morphological flexibility of squamate reptiles, thus the shape of the artificial refuges was important. We selected corrugated slabs with a wave size compatible with the shell shape of young tortoises. Then we compared the data obtained using a standard census (sight searching) *versus* slab searching.

Material and methods

Study species

The Hermann tortoise (*Testudo hermanni hermanni*) is an endangered sub-species (IUCN, 2011) from south-western Europe. Following habitat destruction, this species' range diminished drastically during the last decades, especially in the western parts of the distribution range. In France, the species is now limited to several hundred square kilometers in Corse and the south east (Cheylan et al., 2009; Livoreil, 2009). Despite intensive field monitoring (Cheylan et al., 2009) demographics and field ecology of this species are poorly documented in continental France, especially for juveniles (Guyot, 1996; Livoreil, 2009). Important demographics studies have been successfully carried out in Corsica where population density is relatively high, and in the Punta de la Banya peninsula (Spain) following the re-introducton of the species (Henry et al., 1999; Bertolero et al., 2007a, b; Fernández-Chacón et al., 2011). Adult females lay an average of 4-5 eggs per clutch. The mean body size of hatchlings is 35 mm straight carapace length (CL), and maturity is reached at 10 years (Bertolero

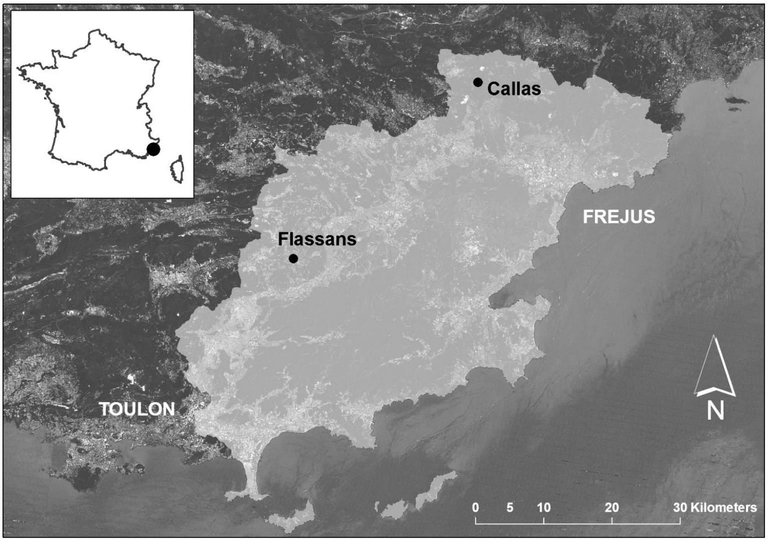

Figure 1. The areas prospected using standard survey from 2001 to 2005 (grey color) correspond to the known distribution range of the species (*Testudo hermanni hermanii*) in south eastern France. The location of the two intensively monitored study sites, Callas and Flassans are indicated.

et al., 2011). Individuals larger than 100 mm (CL) were considered as adults and smaller individuals were considered as juveniles, corresponding approximately to 2-9 year old individuals (Bertolero et al., 2011). Unmeasured tortoises were also classified as adult *versus* juveniles if their body size clearly exceeded ($\geqslant$120 mm CL, $\geqslant$300 g body mass, BM), or was markedly less ($\leqslant$80 mm CL, $\leqslant$150 g BM), than the 100 mm CL threshold. Unmeasured tortoises between these values were not classified.

Field procedure

Between 2001 and 2005, large scale field surveys were performed in 187 different sites spread over 2338 km^2, covering most of the species distribution range in south eastern France (Livoreil, 2009; fig. 1). Each year, standard surfaces of 1.0 km $\times$ 1.5 km were patrolled by 3 to 4 trained people during daylight; these surveys were repeated four times in spring during the main period of activity (for details see Livoreil, 2009). The tortoises were located by sight, searching the most favorable areas, notably exploring semi-open zones and inspecting under bushes and other potential refuges, a technique routinely used for other tortoise species (Livoreil, 2009; Lagarde et al., 2012). The total searching effort represented 604 days of field work. Most of the observed individuals (95%) were captured, measured for body size and body mass (CL and/or BM), individually marked (72%), and rapidly released at the place of capture. These standard surveys provided abundant information (>4500 tortoises observed) and offered an overview of the age population structure across a wide array of habitats and situations (Livoreil, 2009). For simplicity these surveys will be referred as standard surveys.

To compare the results gathered through standard surveys *versus* those obtained using artificial refuges we carefully surveyed two study sites in 2010 and 2011 (Callas and Flassans; fig. 1) using the two techniques. The respective characteristics of the two sites reflect the variations of the habitats across the distribution range. The first site (Callas) is situated near the northeastern limit of distribution. The surveyed surface is approximately 225 hectares and is characterized by a hilly landscape with a dense forest of tall trees (76%), dense thick scrub vegetation (16%), and few open areas (8%). The second site (Flassans) is situated within the northwest region of the distribution range. A 25 hectare surface area was surveyed. The habitat is more diverse and more open compared to Callas; it is represented by a mosaic of grassy meadows (47%), thick scrub vegetation (15%), wooded areas (28.5%), and a temporary lake (9.5%). In 2010 and 2011 we used the standard survey technique in both sites (before and after refuge placement at the Flassans site), however survey intensity was elevated as these two sites were monitored for a total of 344 days in two years by 1-2 trained people. In 2011, one study site (Flassans) was fitted with artificial refuges to enhance the catchability of the young tortoises. The tortoises were processed as described above (78% of the individuals were measured and 100% marked).

The artificial refuge system placed in the Flassans study site consisted of a network of 75 fibrocement slabs (L = 1.20 m, W = 0.80 m) positioned in April 2011 just after hibernation emergence. The slabs were spaced 50 m apart on average; they were placed into potentially favorable microhabitats in the vicinity of natural refuges such as forest edges or near thick bushes. Each slab was positioned on a relatively flat clean herbaceous surface; the irregularities of the substrate and of the herbaceous layer created numerous passages underneath. The wave size of the corrugations offered semi-tubular refuges compatible with small tortoise shell dimensions (width 10 cm, radius 6 cm and length

120 cm, 5 corrugations per slab). Importantly, these refuges were easily accessible and provided tortoises with solid protection against their main predators: indeed dogs, feral pigs and beech martens never displaced the slabs. The network of artificial refuges was inspected (i.e. lifting the slabs) on 25 occasions between April and October 2011, approximately once per week and on a different time than the standard survey. On average one hour was required to check the 75 slabs. Each tortoise found under the slabs was processed as described above.

Analyses

To compare the broad catchability of the tortoises among the main surveys (large scale standard, Callas, Flassans [standard & artificial]) we used both cumulated captures plus recaptures *versus* recaptures only. These values provide an index of the probability to find juveniles *versus* adults in the field during standard inventories (individuals are simply counted); or to better evaluate the catchability of each age class through mark-recapture studies. For the analyses of body size (CL or BM) we discarded recaptures to avoid pseudo-replicates, the data were Log-transformed to meet the normality assumption. Means are expressed with their standard deviation. All the statistical tests were performed using Statistica software 10.0 (StatSoft® Inc. 1984-2011).

Results

The large-scale standard surveys provided total 4877 captures (3497 captures + 1380 recaptures). The intensive standard surveys performed in the two selected sites (Callas and Flassans) provided 885 captures (374 captures + 511 recaptures). The proportion of juveniles varied significantly between the three areas (13.2% in the large-scale survey, 2.7% in Callas, 18.0% in Flassans, contingency table $\chi^2 = 58.8$, df = 2, $P < 0.001$; table 1). Pooling all the data, the average proportion of juveniles was 12.5%. Focusing on recaptures, the proportion of juveniles decreased markedly in all cases, with 3.14%, 0.0% and 4.28% for, respectively, the large-scale, Callas and Flassans surveys. The proportion of recaptures differed between the three standard surveys (same design contingency table $\chi^2 = 9.7$, df = 2, $P < 0.01$). Overall, most of the captures and almost all recaptures were of adults, individuals belonging to this age cohort were markedly easier to locate in the field compared to the juveniles.

The artificial refuges attracted an important number of juveniles (table 1). In 2011, we found 55 small tortoises under the slabs. Importantly 38 of these observations were recaptures, including two individuals marked the previous year. Only 25 days of field work were necessary to find these 55 small tortoises; by comparison a 5.5 times greater searching effort (162 days) was required to find a similar number of juveniles (N = 64) at the same site (table 1) before placement of the slabs. A few adults were found sheltered under the slabs, including two individuals weighing more than 500 g. The elevated proportion of juveniles found under the slabs was significantly greater compared to the values obtained during all the other standard surveys (all $P < 0.001$). Interestingly, from spring to summer the catchability of the juveniles increased when using artificial refuges, but decreased using standard surveys (fig. 2).

Body size analyses provided complementary results supporting the notion that artificial refuges were particularly attractive for the smallest individuals (ANOVA with Log-body

Table 1. Total number of tortoises and juveniles observed (N) using two main survey techniques (standard *versus* the artificial refuge surveys) in different areas and over different time periods. The proportion of juveniles is indicated in parentheses. The large scale area broadly corresponds to the grey area in fig. 1 (see Livoreil, 2009).

Survey technique	Area	Period	Tortoises (N)	Juveniles
Standard (604 days)	Large scale	2001-2005	4877	640 (13.2%)
Standard (82 days)	Callas	2010	187	5 (2.7%)
Standard (100 days)	Callas	2011	342	9 (2.6%)
Standard (75 days)	Flassans	2010	179	35 (19.6%)
Standard (87 days)	Flassans	2011	177	29 (16.4%)
Slabs (25 days)	Flassans	2011	60	55 (91.7%)
Standard + Slabs	Flassans	2011	237	84 (35.4%)

size [CL] as the dependent variable and the survey type [standard *versus* slabs] as the factor; $F_{1,3906} = 100.2$, $P < 0.001$; fig. 3). Note that large individuals were able to shelter under the slabs as the corrugations provided enough space. The body size distribution of the juveniles found under the artificial refuges followed a bell-curve whereas the distribution was highly biased toward larger size in all the other cases (fig. 3). On average, the juveniles found under the slabs were smaller compared to the juveniles found during standard surveys (57.5 ± 12.1 mm *versus* 75.2 ± 17.5 mm, ANOVA Log-body size [CL] of juveniles as the dependent variable and survey type [standard versus slabs] as the category, $F_{1,690} = 15.7$, $P < 0.001$). Similarly, they exhibited lower body mass (53.0 ± 31.2 g *versus* 118.3 ± 71.1 g, same design U ANOVA with juveniles Log-body mass [BM] as the dependent variable, $F_{1,639} = 10.4$, $P < 0.002$).

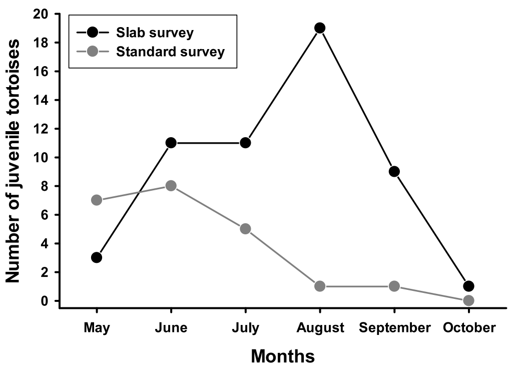

Figure 2. Comparison of the number of juveniles observed in Flassans using the standard survey (grey line and circles) *versus* the artificial refuge technique (black line and circles). The catchability was very low at the end of the active season in October.

Discussion

Our results support the findings of Pike et al. (2008), suggesting that the secretiveness of juvenile reptiles can explain why many field studies have overlooked this age cohort, and that the importance of a relatively high juvenile survival rate was not adequately appreciated. Our large data set confirmed that, on average, juvenile tortoises represent only a small propor-

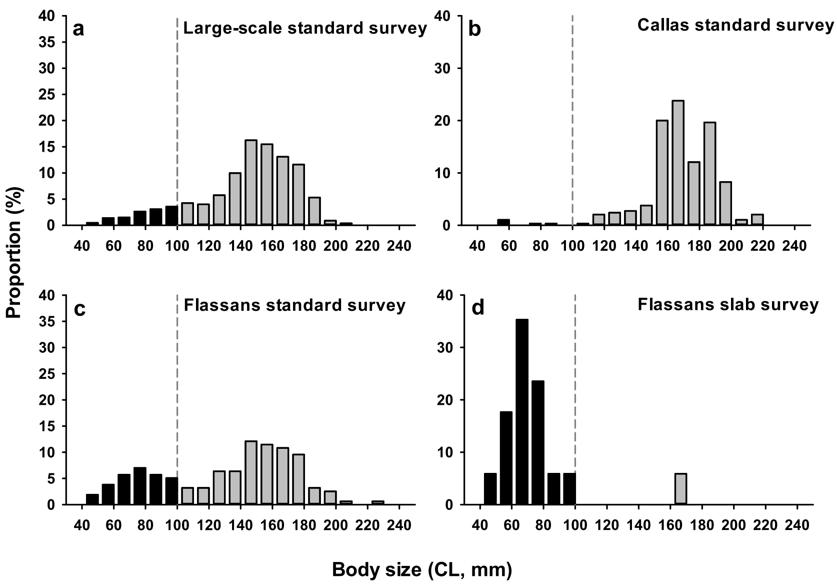

Figure 3. Comparison of the body size distribution of the tortoises observed using the large-scale standard survey (2001-2005) (a), standard survey in Callas (2010-2011) (b), standard survey in Flassans (2010-2011) (c), and using the artificial refuges technique (i.e. slab searching) (d). The X-axis indicates shell length (CL, mm); the Y-axis provides proportion (see text for sample sizes). The dashed vertical line indicates body size at maturity; the black and grey bars show respectively the juveniles and the adults.

Table 2. Number of tortoises (adults AD *versus* juveniles JU) observed (total = captures + recaptures), captured and marked (captured) and recaptured later during the active season (observed again) during the two years of investigation in the Flassans study site. In 2010, only the standard survey technique (i.e. sight searching) was used; in 2011 we combined standard and artificial refuge surveys techniques. The proportion of recaptures is indicated in parentheses.

Year	Age cohort	Total	Captured	Observed again
2010	AD	144	74	70 (48.6%)
2011	AD	148	61	87 (58.8%)
2010	JU	35	30	5 (14.3%)
2011	JU	84	43	41 (48.8%)

tion of field captures (12.5%), and that recapture rate is extremely low (0%-4.3%). Taken together, these results lead to the deceptive impression that only few juveniles might survive each year, and precluded estimating accurate survival rates (few studies provided adequate information for juveniles; e.g. Fernández-Chacón et al., 2011). However, the use of artificial refuges as a novel survey technique considerably increased the ability to detect free living juveniles; moreover our results suggest that a substantial cohort of young individuals is a key component of population functioning.

Importantly, the artificial refuges increased recapture rate: 49% of the juvenile observations were recaptures (table 2), notably in late spring and in summer when juveniles are the most secretive (fig. 2). Many new juveniles were nonetheless found under the slabs through a modest searching effort: in 2011 we found 19 different small tortoises under the slabs during 25 searching-days *versus* 24 individuals during 87 standard searching-days (representing a >2.5 increase). Flassans was intensively monitored during two consecutive years using the two techniques in parallel. The examination of the list of captures and recaptures over two years revealed that the values were remarkably similar for the adults (<3% difference for the total number of adults observed) while the values increased markedly for the juveniles (>58% increase for the total number of juveniles observed, table 2). Importantly the increase of the catchability of the juveniles found under the slabs did not decrease the number of juveniles observed using classical survey (comparing 2010 and 2011, table 1); thus the two techniques were complementary. In other words, we can discard the possibility that juveniles found during standard surveys were actually displaced to shelter under the slabs and therefore by default excluded from the standard survey by moving into the slab survey. The slabs enabled us to recapture the juveniles at an equivalent rate (approximately 0.5) compared to the adults. This result, although preliminary, suggests that when the capture bias between the main age cohorts is attenuated, the age-specific probabilities of recapture converge toward relatively similar high values, and this trend fits remarkably well with the predictions of Pike et al. (2008) where adult and juvenile survivals were close to each other.

Other field studies documented the fact that artificial refuges, or particular climatic events, can drastically modify the incorrect albeit widespread perception that reptile populations are strongly adult-biased. For instance, several hundreds of fibrocement slabs positioned in a temperate forest in Western Central France increased considerably the juvenile catchability of three snake species (Bonnet, Naulleau and Shine, 1999); artificial burrows were heavily used by juvenile ocellated lizards (Grillet et al., 2010); and high numbers of juveniles in two sea-krait species were revealed after they left their refuges after downpours following a drought (Bonnet and Brischoux, 2008). Under favorable conditions, important numbers of juvenile reptiles can be observed in the field, illustrating that they represent an important component of their population. Conversely, their extreme secretiveness is a well established phenomenon in most species.

The low visibility of juveniles can be explained by their small size, but this explanation is clearly insufficient as they are easily found under favorable conditions. Most likely, the low detectability of young reptiles can be explained by life history traits. Compared to conspecific adults, juveniles are vulnerable to predation, dehydration, and overheating; on the other hand, they are not engaged in the demanding processes of reproduction. Therefore, natural selection should promote extreme secretiveness associated with a high survival until maturity. Our current results on tortoises along with previous studies on snakes show indeed that juveniles intensively use the refuges available in their habitat (natural or artificial). In the current study, the artificial refuges covered only several square meters of substrate and they were dispersed over several hectares of complex natural habitat with abundant and dense vegetation. Apparently, the juveniles were strongly attracted to the artificial refuges. We hypothesize that this attraction was due to the anti-predator effect of the slabs (e.g. dogs and boars cannot search under slabs whereas they can investigate within bushes); in addition the great range of body temperatures that the individuals can easily reach underneath slabs requires only limited displacements (Lelièvre et al., 2010). In support of these notions, many young tortoises were recaptured under the slabs, and we did not find any injured juveniles under the artificial refuges. The safety offered by artificial refuges might represent a means to improve juvenile survival, especially during the crucial early post-hatchling period (Butler and Sowell, 1996; Pike and Seigel, 2006; Tomillo et al., 2010; Bolten et al., 2011).

The strong difference in population structure between Callas and Flassans revealed both by standard and slab surveys suggest strong divergences in terms of juvenile recruitment and population functioning. Due to the abandonment of pastoral and forest management the habitat in Callas shifted from favorable open mosaic vegetation toward an unmanaged closed habitat dominated by dense forest with a strong decline of thick bushes. Likely, such habitat change influenced population structure of *T. hermanni* characterized by very low number of juveniles and dominance of large and old individuals. Nesting sites and the microhabitats suitable for the juveniles (very thick bushes in open areas) are now scattered and they represent less than 3% of the surface. In addition, Callas contains a high population of predators, particularly feral pigs. In contrast, the mosaic landscape of Flassans offers numerous suitable microhabitats, especially numerous and well-developed spiny *Rubus* bushes. The difference in population structure between the two sites likely reflects these divergences in habitat quality. Although we did not set up the slab network in Callas, it is very likely that we would have found very few juveniles regardless of the technique used. We base this conclusion on the very strong difference in the number of juveniles observed in each zone despite similar intensive searching effort during two consecutive years: we found many tortoises in Callas but very few juveniles despite the fact that small tortoises would have been easily located by sight due to the lack of thick bushes.

Callas and Flassans were respectively situated at the extremities of a gradient with populations exhibiting strong evidence for low *versus* high recruitment rates. The lack of young tortoises in Callas cannot be attributed to a deficit of reproductive individuals. More than 270 adults have been marked and the sex ratio was equilibrated ($\chi^2 = 0.44$, df $= 1$, $P = 0.51$); females probably laid their clutches in the field during the past decades, but most eggs/neonates were quickly removed from the population. Egg predation was apparently high in Callas: the three nests found in Callas were devastated by feral boars (N = 1) and beech martens (N = 2); whereas only one among three nests monitored in Flassans was subjected to predation. In Flassans we marked a much smaller number of adults (N = 116) than in Callas, but we found many more juveniles. Furthermore, the bell shape of the juvenile body size distribution observed in Flassans was expected if we assume that an important proportion of the eggs actually hatched and that a substantial proportion of the neonates were incorporated in the young juvenile cohorts. As a possible result, the mean body size of the adults (both sexes) was also lower in Flassans compared to

Callas that contains essentially large and presumably old tortoises (Anova, with Log-CL as a dependent variable, sex and site as the factors: $F_{1,252} = 7.50$, $P < 0.01$). Fecundity increases with body size in tortoises (Hailey and Loumbourdis, 1988; Wallis, Henen and Nagy, 1999; Bertolero et al., 2007a) thus a larger number of females may well deposit larger clutches in Callas compared to Flassans, unsuccessfully however. Although the strong differences between Callas and Flassans entail strong limitation to compare the two sites (e.g. comparing the two techniques; large tortoises cannot easily shelter under slabs), these two extreme situations offer useful information to interpret results from surveys and to set up managements actions.

This strong contrast between sites is indeed representative of the general decline of the Hermann tortoise over the entire distribution range during the last decades. The large scale surveys generated a population structure trend, highly biased toward adults and with a marked deficit of the smallest juveniles. Likely, the longevity of the tortoises enabled the persistence of large individuals in most places despite a lack of recruitment; but our data are alarming from a long term perspective.

Conclusion

Further investigations focusing on the juveniles are urgently needed. The use of artificial refuges is a useful technique for such an endeavor. First, increasing juvenile catchability is essential to perform more accurate inventories in order to indentify priority sites for conservation (e.g. nurseries). Second, implementing more realistic survival rates into PVA analyses recaptures of juveniles are required. Finally, different models of artificial refuges should be developed (e.g. well-concealed shelters to limit illegal collection) and tested to enhance the survival of the most vulnerable age class of tortoises. This approach would be particularly beneficial to sites such as Callas where a lack of refuges might be detrimental to the juvenile age cohorts. Checking slabs is relatively rapid, and hence it can be easily combined with more intensive standard searching effort to increase the likelihood of capturing larger individuals in order to obtain a more accurate picture of the studied populations. Developing these conservation tools is important for the evaluation of field management actions, notably for reintroduction or reinforcement programs that are currently based on very rough estimates of crucial juvenile life history traits (Freilich et al., 2000; Bertolero, Oro and Besnard, 2007; Michael, Fefferman and Averill-Murray, 2009).

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