

A management plan for a declining population of the Souss valley tortoise in an arid steppe-land of west-central Morocco

Nawal Hichami^{1,2}, Mohammed Znari^{2,3,*}

¹ Laboratory of Biotechnology & Sustainable Development of Natural Resources, Polydisciplinary Faculty of Beni Mellal, Sultan Moulay Slimane University, Mghila PO Box. 592, Beni Mellal 23000, Morocco.

² Laboratory “Water, Biodiversity & Climate Change”, Department of Biology, Faculty of Science, Semlalia, Cadi Ayyad University, Bd Prince Moulay Abdellah. PO Box 2390, 40000 Marrakech, Morocco.

³ Natural History Museum of Marrakech, Cadi Ayyad University, Ave Allal El Fassi. PO Box 550, 40000 Marrakech, Morocco.

*Correspondence: znarim@gmail.com

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The endangered Moorish tortoise *Testudo graeca* is the unique terrestrial chelonian species in Northwest Africa. In west-central Morocco, the endemic subspecies, the Souss valley tortoise *T. g. soussensis*, occupies semi-arid to arid low-quality habitats, and is subject to serious threats. A long-term mark-recapture programme from 2001 to 2012 allowed estimating population size and structure, sex ratio, and survivorship in one of the well-known populations in a degraded and overgrazed arid steppe-land of west-central Morocco. Spring population size considerably decreased to more than half in less than 10 years, with a mean density lower than 3 ind.ha⁻¹ in 2012 compared to its last known density estimated in 2003. In spring 2012, the population structure exhibited an unbalanced male-biased sex ratio (61:39) and a scarcity of juveniles (<5%). We identified five major conservation problems in the study area: (i) habitat destruction and overgrazing; (ii) over-collecting of tortoises for pet trade, (iii) direct disturbance; (iv) tortoise handling mostly for field research, and (v) increased extinction risk due to the small population size. We carried out a population viability analysis using the VORTEX software based on published and obtained data on population and life history parameters. With no management action, the population will go extinct during the forthcoming 40 years after the last estimate. The most efficient management option for a long-term persistence of the population would be reducing the nest and neonate mortality by 90%. To attenuate the impact of the threatening factors, we developed a management plan that includes population reinforcement and habitat restoration options.

Key words: arid steppes; management plan; population characteristics; population viability; Souss valley tortoise; threats.

Tortoises show a relatively long reproductive lifespan, a delayed maturity, and a low hatching success and juvenile survivorship. These demographic traits make tortoise’s populations particularly sensitive to the loss of mature individuals. Terrestrial chelonians are often threatened by human activity, such as pet trade, hunting

for food, or habitat destruction (VAN ABBE-MA, 1997) resulting in a strong decline of many local populations. During the last decades, numerous management plans have been implemented for numerous tortoise species. For instance, BOARMAN (2003) and DOAK *et al.* (1997), studied the management strategies for declining desert

tortoises (*Gopherus agassizii*) populations in the Mojave Desert, California (USA), through reducing common raven predation and human disturbance in concert with actions that reduce other causes of desert tortoise mortality to aid the long-term recovery of their populations.

The Moorish tortoise *Testudo graeca* (L., 1758) is considered as one of the most charismatic species of the circum-Mediterranean fauna. However, this species is endangered across its entire range (classified, as vulnerable (VU) by IUCN (2018)) and the main threats are habitat loss (IUCN, 2018) and collection for pet trade (LAMBERT, 1979; ZNARI *et al.*, 2005; PÉREZ *et al.*, 2011). *Testudo graeca* from North Africa, Greece and Spain is a typical example of this general trend (ERNST & BARBOUR, 1989; IVERSON, 1992). Although inadequately quantified, all experts agree that populations are declining markedly in almost all areas (STUBBS, 1989; LAMBERT, 1995). In this context, precise information on the demographic characteristics and vulnerability of populations are urgently required to eventually sound the emergency alarm and to set up conservation and management plans. We particularly need to better understand the proximate causes of such decline. Unfortunately, our current knowledge on the population ecology and long-term demographic variations of this species is very limited. For example, intensive studies have been conducted on very few populations, notably in Southern Spain (ANDREU, 1987; KELLER, 1993; DIAZ-PANIAGUA *et al.*, 1995, 1996, 1997; KELLER *et al.*, 1998; ANDREU *et al.*, 2000) and Greece (HAILEY 1988; HAILEY *et al.*, 1988, 1990, 2000). In North Africa, there are a few de-

mographic studies on *T. graeca* in Morocco (LAMBERT 1969, 1981, 1982; BAYLEY & HIGHFIELD, 1996; EL MOUDEN *et al.*, 2002; SLIMANI *et al.*, 2002; BEN KADDOUR *et al.*, 2006) and Algeria (ROUAG *et al.*, 2007). The loss of suitable habitats for this species in the region (mostly due to overgrazing) is particularly important and tends to increase over time (QUÉZEL, 2002).

The Souss valley tortoise, *T. g. soussensis*, an endemic subspecies to west-central Morocco, inhabits arid areas of low quality (ANADON *et al.*, 2012), mostly in the Souss valley, the Atlantic coastal area of Essaouira and the inland arid-steppes of the Haouz plain and central Jbilet Mountains around the Marrakech city (ZNARI & HICHAMI, 2018). This endemic tortoise has been qualified as a strict semiarid taxon since the probability of its occurrence plums between 300 and 400 mm of annual rainfall (ANADON *et al.*, 2015). Preliminary surveys indicated a considerable regression of the population of this subspecies in these latter areas. Such a regression is presumably due to a combination of unfavorable climatic conditions (chronic droughts), excessive urbanization and pet trade in these touristic abovementioned locations during the previous two decades. In spring 2003, BEN KADDOUR *et al.* (2006) reported in an arid and overgrazed steppe area close to Marrakech city, west-central Morocco, a relatively high local population density of around 6 ind./ha (nearly 200 individuals concentrated within a central 33-ha area).

Even though this species is protected from over-collection, many shops in Marrakech showed hundreds of tortoises for sale (ZNARI *et al.*, 2005). Most (65.5%) of

these tortoises were small sized (SCL < 100 mm), and were likely young (immature) tortoises (age: from 2 to 9 years). In addition, its natural habitat is strongly degraded due to overgrazing along with cutting of Spiny jujube (*Ziziphus lotus*) bushes that are used both as thermal refuges and as a good supply of “pantry food” (LAGARDE *et al.*, 2012).

Moreover, the climate change that the Marrakech area has been experiencing during the last decades (AIT BRAHIM *et al.*, 2017), would have undoubtedly affected the steppe-lands and their wildlife, including tortoises. Indeed, and according to AIT BRAHIM *et al.* (2017), in the arid area of Marrakech climate has changed during the last decades (since 1961) with a global warming reaching +1.5°C, but a decrease in annual rainfall of more than 22%. In addition, there was an increase in frequency and intensity of drought periods. An evolutionary trend towards drought in Marrakech is clearly noticeable, because the occurrence of droughts became increasingly more frequent after 1980, especially in Marrakech. This observation demonstrates longer periods of intra-annual drought and therefore an increase of their persistence time. Hence, the increase of droughts is anticipated in the area (AIT BRAHIM *et al.*, 2017).

We predict that, due to climate change stress (drought) and human pressures, this population has declined with a potential mid- to long-term extinction risk. The present study is aimed at obtaining basic demographic data for a population viability analysis and for establishing conservation and restoration guidelines. We developed a management plan to allow the long-term

(i.e., 100 years) survival of *T. g. soussensis* in arid steppe-lands in the Jbilet mountains, west-central Morocco.

MATERIALS AND METHODS

Study site

The study area is located in the central Jbilet Mountains about 25 Km north to Marrakech, west-central Morocco (31° 37'N, 8°02'W; and average of 580 m a.s.l.). The region is arid, with a mean annual rainfall of 240 mm, occurring mostly between September and February (EL MOUDEN *et al.*, 1999; ZNARI *et al.*, 2002). Average air temperature in the hottest month (July) is 39°C and the minimal annual temperature (January) is normally around 0°C (LE HOUÉROU, 1989; EMBERGER, 1933). Plant cover consists mainly of Jujube bushes (*Ziziphus lotus*), with some widely scattered Morocco-gum (*Vachellia gummifera*) and bridal broom (*Retama monosperma*). Most of the habitat is open, hard bare ground with stony soil on the flat and low hillsides that surround small sandy, pebbly or stony wadies (small rivers). Seasonal over-grazing by domestic livestock (sheep and goats) strongly affects the vegetation. A simple visual inspection of the study area reveals two major and different plant assemblages: a relatively rich and diversified plant community under Jujube, protected against over-grazing by the spiny structure of this shrub, and a less diversified plant community out of the Jujube, with a very scattered plant cover (see EL MOUDEN *et al.*, 2005).

Sampling methodology

In order to estimate the mean annual adult survival rate over at least one gener-

ation, we conducted a long-term multiple mark-recapture sampling from 2001 to 2012; we intensively captured tortoises once every spring during 3 to 5 consecutive days. In 2012, we carried out a short multiple mark-recapture biweekly series from late February to mid-May to assess the spring final population size. We referred to the first initial population size estimate obtained in spring 2003 for the same population as in BEN KADDOUR *et al.* (2005) to highlight its demographic trend. We established the mean population structure from year-round sampling during 27 to 43 days per year in 2011 and 2012. We compared the obtained structure to those reported for the same population in 2001 (ZNARI *et al.*, 2005) and 2003 (BEN KADDOUR *et al.*, 2005).

Tortoises were caught by hand, sexed (based on morphological sexual dimorphism traits as in CARRETERO *et al.*, 2005; ZNARI & HICHAMI, 2018), weighed (to the nearest 0.1g), measured with a caliper for carapace length (CL), width (CW) and height (CH) (to the nearest 0.1mm), and individually marked with notches on their marginal scutes according to a numerical combination code. The individual age was estimated from the number of annuli on the costal scutes (ZNARI *et al.*, 2005).

Data analyses

We developed a management plan using a conceptual model according to Sutherland's approach (SUTHERLAND, 1996). Briefly, we tried to identify the major factors that might hamper the long-term population persistence (over 100 years), defined the causes of the main acting factors, and assessed possible measures to keep

their impacts to a minimal level.

We used Vortex 9.99 (MILLER & LACY, 2005) to simulate the viability of the studied population. We used data obtained from our fieldwork (current population size, survival rate, sex ratio, clutch size, age at sexual maturity, age structure) and from other published studies (Doñana National Park in ANDREU, 1987; KELLER 1993; DIAZ-PANIAGUA *et al.*, 1995, 1996, 1997; KELLER *et al.*, 1998; ANDREU *et al.*, 2000) such as initial population size, percent of breeding females annually, maximum reproduction age, and juvenile's survival rates (Table 1). We used MARK 8.0 (COOCH & WHITE, 2017) for estimating the survival rates from the mark-recapture histories of 233 males and 264 females (2001–2012). Given the small number ($n = 29$) of marked juveniles, these were excluded from the analyses.

We derived the parameter estimates from a model where the recapture rate was constant over time and similar for all tortoises (i.e., a single recapture parameter was estimated for both males and females). Survival rate did not vary over the years but was different between sexes (model $\Phi(g) p(\cdot)$; LEBRETON *et al.*, (1992)). For an approximation of environmental variation (EV) in survival, we estimated survival rate from a model with temporal variation in this parameter but no effect of group (model $\Phi(t) p(\cdot)$). We evaluated, from the Box D in the Vortex manual (MILLER & LACY, 2005), that EV was less than 1%, which was considered as a conservative estimation in the simulations. Accurate information on many population parameter estimates in tortoises are lacking (SHINE & IVERSON, 1995), making it difficult

Table 1: Values of population parameters entered into the population viability analyses using the Vortex software (MILLER & LACY, 2005).

Parameter	Basic scenarios	References
Carrying capacity (K)	192	BEN KADDOUR, 2003
N initial	88	Estimated from mark-recapture data.
Hatching success	82.4%	DIAZ-PANIAGUA <i>et al.</i> , 1997 (Doñana)
Structure of population in 2012 (Spring)	Of 0 to 6 years: 5.06% Adult male de 7 years and up: 58.23% Adult females of 9 years and up: 36.71%	
Age-specific mortality		
Females	0-6years: 98.7-90,3% (94.5%) per year 0-6 years: 98.7-90.3% (91%) per year 11 years and up 19% / years, DS: 1%	DIAZ-PANIAGUA <i>et al.</i> , 2001 BALLESTAR <i>et al.</i> , 2004 Present study, estimated from mark-recapture data. Age at sexual maturity from ZNARI <i>et al.</i> (2005)
Males	0-6 years: 98.7-90.3% (94.5%) per year 0-6 years: 98.7-90.3% (91%) per year 8 years and up 14%/ years, DS: 1%	DIAZ-PANIAGUA <i>et al.</i> , 2001 BALLESTAR <i>et al.</i> , 2004 Present study, estimated from mark-recapture data. Age at sexual maturity from ZNARI <i>et al.</i> (2005)
Inbreeding	No	
Correlation Environmental Variation (EV) (reproduction) – EV (survival)	Yes	Good survival years = good reproduction years.
Catastrophes	No / Yes	Drought 10% (negative effect on survival 25% and on reproduction 25%). Fire reduces reproduction by 50% and survival by 75%.
Mating system	Polygamous	
Age at first reproduction, males	7 years	BEN KADDOUR <i>et al.</i> , 2006
Age at first reproduction, females	9 years	BEN KADDOUR <i>et al.</i> , 2006
Maximum breeding age	20	ZNARI <i>et al.</i> , unpublished data
Sex ratio at birth (% males)	50% at 30-31°C	PIEAU, 1975
Maximum clutch size per year	7	HICHAMI <i>et al.</i> , 2016
Estimated from maximum	SCL (190 mm)	Present study
Reproduction density-dependent?	No	Optimistic scenario
% females breeding per year	93.3% (EV=0,1)	DIAZ-PANIAGUA <i>et al.</i> , 1996
SD breeding annually	10%	No data available
Clutch size	3.3±1.7 (1–5)	HICHAMI <i>et al.</i> , 2016
Clutch size	3.48±0.92	DIAZ-PANIAGUA <i>et al.</i> , 1996
Number of clutches per year	4	DIAZ-PANIAGUA <i>et al.</i> , 1996
Maximum number of eggs per year	19	DIAZ-PANIAGUA <i>et al.</i> , 1996
Mortality rate nests	95.5%	DIAZ-PANIAGUA <i>et al.</i> , 1997
SD in mortality rate due to EV	1.00%	EV in survival
All adult males in the breeding pool?	Yes	Optimistic scenario
Start at a stable age distribution?	No	Estimated from size distribution
SD in K due to EV	10	No data available
Trend in K?	No	Optimistic scenario
Harvest in the population?	No	
Supplement the population	No/yes	

to construct realistic population viability analyses (BOYCE, 1992). Thus, we firstly considered an optimistic simulation (95% females breeding every year, no catastrophes) and carried out a sensitivity analysis. Values entered in the simulations are shown in Table 1. Density-dependent reproduction was not considered in our model, but we used a carrying capacity of 192 ± 20 tortoises corresponding to the highest last estimated population size (BEN KADDOUR *et al.*, 2006). We ran all simulations 1000 times for 100 years.

We carried out an analysis to estimate how different management options could impact the population survival probability. We modeled the fate of the studied population, starting with a conservative scenario (Table 1). We considered a total population initial size of 88 with a known age structure (in 2012). We also tested other scenarios with different management options: a) reducing mortality of neonates and juveniles to i) 25% and ii) 50%; b) two catastrophes, namely drought and bush fire (the first occurring with 0.05 annual probability, reducing reproduction and survival by 25%; the second with 0.01 annual probability, reducing reproduction by 50% and survival by 75%); c) supplementation (restocking) of the population during 10 years (from year 10 to 20), with 25 one-year old males and 25 one-year old females per year; d) reducing nest and neonate mortality to 90%.

RESULTS

Identifying the main direct threats and their causes

According to our study, a conceptual model of the management plan for the Souss valley tortoise *T. g. soussensis* in cen-

tral Jbilet Mountains, west-central Morocco is summarized in Figure 1. Here, several factors are highlighted to be concerned as principal causes of threats.

These factors constitute by far the strongest threats facing the persistence of the Souss valley tortoise in west-central Morocco. There are many direct and indirect forces contributing to this threat, including, but not limited to:

a) *Habitat fragmentation* (e.g., railways, surfaced roads and rural paths). Potentially causes road mortality, reproductive isolation, small and discontinuous populations, and edge effects that may increase predation. Habitat destruction from activities such as urbanization and agriculture intensification, potentially causes direct mortality and/or displacement of tortoises to less favorable habitats. Habitat modification, either deliberate or not, include conversion of Jujube steppes or agricultural habitats leading to overgrazing, shrub/hardwood encroachment and establishment.

b) *Over-collecting for illegal trade* (see ZNARI *et al.*, 2005; NIJMAN & BIRGIN, 2017) and *handling for recreational or scientific* (especially during the last two decades) purposes (ZNARI & HICHAMI, 2018). Handling tortoises can cause urination due to stress and then loss of precious water reserves from the urinary bladder. This leads to an acute hypo-hydration, which is a cause of mortality, particularly in juveniles.

c) *Parasites, diseases and predation*. Most of the tortoises we handled during the study period were infested, at various degrees, with ticks, especially *Hyalonema aegyptium* (Family Ixodidae). Many cases of massive infestation were observed in collected tortoises.

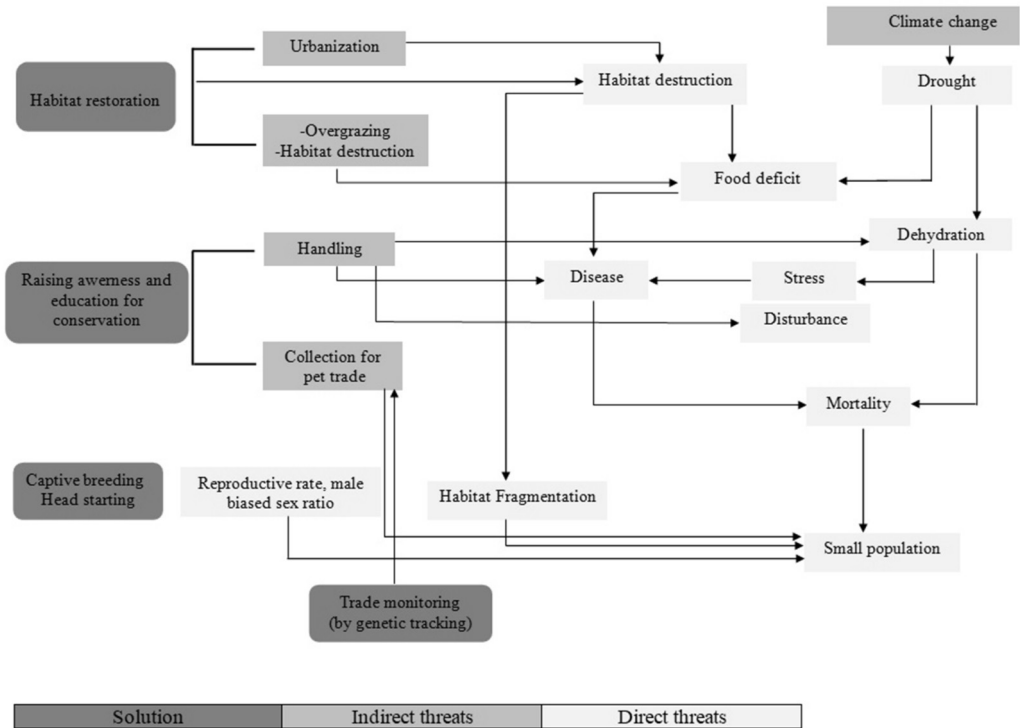


Figure 1: Conceptual model of the management plan for the Souss valley tortoise *Testudo graeca soussensis* in central Jbilet Mountains, west-central Morocco.

Predation, while almost exclusively to eggs, hatchlings, and small juvenile tortoises, continues to be an ever-present threat. In hatchlings, and to a lesser extent, in juveniles the shell is soft and/or not solid enough to resist to many predators such as canids, birds or even snakes.

d) Climate change. During our study period (2001-2012), the area experienced highly variable rainfall and recurrent droughts. Overall, observed climate trends in Marrakech area over the last 60 years identified a clear tendency towards higher temperatures and lower rainfall (AIR BRAHIM *et al.*, 2017). This would affect pri-

mary production and then the quality (i.e., water content and chemical composition) and availability of food resources for tortoises, which are rather specialist herbivorous feeders (EL MOUDEN *et al.*, 2006). This would also have a negative impact on body condition, hypo-hydration and osmotic stress (ZNARI & HICHAMI, in prep.).

e) Small population size, population structure and adult annual survival rate. Seventy-nine individuals (including 4 juveniles, 46 adult males and 29 adult females) were tagged and then recaptured one to five times depending on each marked individual in successive sessions during the late

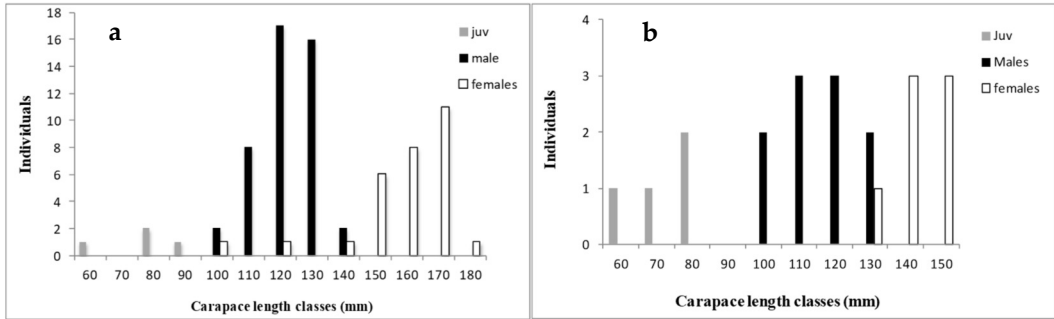


Figure 2: a) Size distribution of *Testudo graeca soussensis* of living individuals in the central Jbilet population, west-central Morocco; b) Size distribution of *Testudo graeca soussensis* of dead individuals in the Central Jbilet population, west-central Morocco. Size distributions are represented for juveniles (grey bars), adult and sub-adult females (white bars) and adult and sub-adult males (black bars).

winter-spring activity period (February-May 2012). The estimated mean total population size in spring 2012 was 88 ± 4 ind. (95% confidence interval: 84-93) corresponding to an average population density of 2.7 ind./ha.

The apparent frequency distribution of the captured tortoises was characterized by the scarcity of juveniles (age: 1 to 5 years), which accounted only for 5% of the total population. The majority of individuals observed were adults (95%) with a carapace length > 100 mm. The age-class structure among male and female subpopulations was significantly different ($\chi^2 = 18.67$, $p < 0.05$). Females were significantly distributed in larger classes ($\chi^2 = 63.4$, $p < 0.001$), with the largest adult female and male reaching the respective sizes of 190 and 148 mm. The adult sex ratio is male-biased to 1.56 (61% of males).

During the study period, juveniles, adult males and adult females represented unequal group frequencies among years ($\chi^2 = 36.17$, $p < 0.01$). When juveniles were

excluded, adult males and females were found in unequal frequencies among years ($\chi^2 = 3.26$, $p > 0.05$). The SCL of tortoises (including juveniles) ranged from 59 to 202 mm. The largest male size class was 140–145 mm, while the largest size classes for females and juveniles were 180–185 and 59–90 mm, respectively (Fig. 2a). However, except for females, SCL frequencies of each group were normally distributed ($\chi^2 = 0.198$, $p > 0.20$). As for dead tortoises, 21 individuals were found during the whole study period: juveniles 19% (4 ind.), adult males 47.6% (10 ind) and adult females 33.3% (7 ind). (Fig. 2b).

Mean annual survival rates for adult male and female tortoises, estimated during the period of 2001-2012, were respectively 0.842 ± 0.131 (confidence interval: 0.743-0.978) and 0.793 ± 0.162 (confidence interval: 0.634-0.987).

Population viability analysis

We carried out this analysis to estimate how different management options could

affect the population survival probability. The results of the simulations are shown in Figure 3. We modeled the fate of the studied population in the Jbilet Mountains, starting with a conservative scenario (Table 1). We considered a total population initial size of 88 with a known age structure (in 2012). The basic scenario, with no management option, revealed that in 18 years 100% of the Jbilet population will be extinct. The model showed a high sensitivity to variations in juvenile survivorship: while a reducing mortality of juveniles by 25% showed no significant difference with the basic scenario, reducing the value to 50% delayed the extinction time to around 40 years. Similarly, the supplementation option of the population did not result in any significant improvement of the long-term maintenance probability of the population with an extinction time of slightly less than 40 years. If drought and bush fire catastrophes are considered, the population will go extinct in around 20 years, which is not different from the basic scenario and the option management of reducing juvenile mortality to only 25%. On the other hand, when reducing nest mortality by 90%, the probability of survival reaches 100% in 100 years.

DISCUSSION

As indicated in Figure 1, destruction, modification, or curtailment of habitat are the axial factors responsible for the decline of the studied population of *T. g. soussensis* in central Jbilet Mountains, west-central Morocco. The potential causes of the aforementioned indirect effects are mainly due to the decline of available forage and

groundcover (BAYLEY & HIGHFIELD, 1996; LAGARDE *et al.*, 2012). In addition, the loss of jujube bushes restricts the availability of thermal refuges that protect tortoises from dehydration and overheating (LAGARDE *et al.*, 2012; MOULHERAT *et al.*, 2014). In other parts of Morocco, like the Jbilet Mountains, the jujube, *Z. lotus*, suffers from officially promoted programs of removal. *Testudo g. soussensis* is threatened by such habitat loss, as tortoises must navigate between microhabitats to find essential feeding resources and thermal refuges (LAGARDE *et al.*, 2012).

Moreover, in recent years some parts of the habitats were destroyed as a consequence of roads construction, and most of the remaining patches are heavily damaged. Some bushes that could be a good habitat for the tortoises are now separated by traffic areas. Therefore, they cannot be reached by natural dispersal. Again, an environmental education plan seems appropriate to minimize human disturbance to tortoises.

Another principal factor of the studied population decline was the over-collection for illegal trade and handling for recreational, scientific, or educational purposes. Despite legal protection under the Moroccan law (n°29-05 on the protection of wildlife and monitoring of its trade, 2011), vandalism and collection of Moorish tortoises by humans for medicinal use (NIJMIN & BIRJING, 2017), food or as pets (ZNARI *et al.*, 2005), were cited as threats to the species, and commercial collecting was at one time considered significant. While illegal collection of Moorish tortoises still occurs and such collection could possibly impact local populations, there is little quantitative evi-

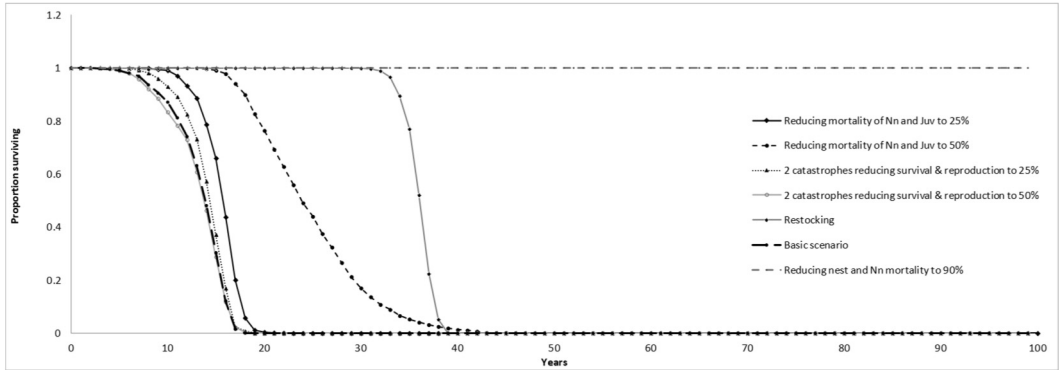


Figure 3: Results of the population viability analysis for the Souss valley tortoise population in the central Jbilet Mountains, west-central Morocco. (Nn: Neonates and Juv: Juveniles).

dence specific to this threat (ZNARI *et al.*, 2005). Hence, the impact of collecting native populations is still unknown. ZNARI *et al.* (2005) suggested that older, larger tortoises may have been removed in the past and now smaller tortoises are being taken. This has obvious negative consequences for these tortoise populations because not only are the large, most fecund females mostly absent, but also now the younger tortoises that could take their place are being removed. If these populations do not experience any additional collecting, particularly of younger individuals, the populations likely will be self-sustaining. However, a return to over-collecting could cause these populations to become extinct. *Testudo g. soussensis* may be highly sensitive to repeated illegal harvesting. Although, in certain situations (i.e., high female fecundity in a poorly degraded landscape), a moderate level of harvesting may be sustainable (HAILEY, 2000). Nonetheless, LAMBERT (1981) found that in North Africa, the population sizes and structures were affected by the intensive harvesting during the 1960s and 1970s.

Other potential factors are parasites, diseases and predation that are considered sources of threat for the studied population. Most of the tortoises in central Jbilet Mountains, were infested by ticks. A massive parasitism, mostly by the species *Hyalonema aegyptum* (up to 10 ticks per tortoise), the family Ixodidae, has been reported in different populations of west-central Morocco (EL MOUDEN *et al.*, 2019). These infesting ticks, were found to carry various microorganisms (KIREÇCI *et al.*, 2013). According to these authors, and in addition to various specific infections, the ticks can act as mechanical or biological vectors of different bacterial pathogens in both tortoises and humans. In addition, 92% of the tortoises from west-central Morocco were infested by gastrointestinal parasitic nematodes (LAGHZAOUI *et al.*, 2021).

Several diseases have been documented in the Moorish tortoise. Free-living Moorish tortoises might suffer from upper respiratory tract disease (URTD), a pathology primarily caused by *Mycoplasma agassizii* (LECIS *et al.*, 2011). In addition, *Salmo-*

nella bacteria were found in almost 90% of tortoises from central Jbilet Mountains (HIDALGO-VILA *et al.*, 2008). In terrestrial chelonians, *Salmonella* species are considered part of the intestinal flora, and do not cause any clinical signs. However, in immune-compromised animals, they may cause salmonellosis, an important reptilian zoonosis.

Predation on hatchling and juveniles of *T. graeca* has already been documented for several birds and mammals (SCHLEICH *et al.*, 1996; GEFFEN & MENDELSSOHN, 1997; KELLER *et al.*, 1998). Many predators might potentially have an impact that has not been fully documented. Predators include feral dogs, foxes, raptors, and other species. In west central Morocco, hatchlings of *T. g. soussensis* were found impaled by the Grey Shrike *Lanius meridionalis*, on spiny shrubs and Argan trees *Argania spinosa* (BARJE *et al.*, 2005).

Climate change is a major factor to be taken into account in the studied population decline. Increasing environmental temperature and reduced precipitation would negatively impact the primary productivity and water availability in the steppe ecosystem, which in turn will affect tortoise biology and ecology (i.e., thermal regulation: LAGARDE *et al.* (2012), and osmoregulation: HICHAMI (2017); unpublished data). Climate change would also directly or indirectly affect some other causes of population regression. In such situation of aridification, tortoises will be more subjected to tissue hypo-hydration and osmotic stress, and general weakening related to nutritional deficiencies due to lower primary production and plant quality (ZNARI & HICHAMI, in prep.). Hypohy-

drated tortoises reach a critical threshold that is fatal to them from diseases due to increased susceptibility to pathogens and parasites associated with a deficiency of the immune system. The studied inland populations of west-central Morocco occur at the southern distribution limit of *T. graeca* in Morocco (ANADON *et al.*, 2012). Here, high temperatures are very common in spring, suggesting that climate may favor the production of more females. Also, potential differences in mortality and emigration rates between sexes could be involved.

The studied population of *T. g. soussensis* in central Jbilet Mountains, suffers from other main problems: the population size is quite small, the adult sex ratio is male-biased (61:39) and the hatchling/juvenile mortality is probably very high (based on the very low proportions of these classes in the population). About ten years before, ZNARI *et al.* (2005) and BEN KADDOUR *et al.* (2006) reported, respectively in spring 2001 and 2003, a balanced sex ratio for this same population in the Jbilet Mountains. We are confident that our sampling is not male-biased; both males and females were searched for at the same time with the same capture effort; catching was rather exhaustive. Thus, the recorded sex ratio is the real sex ratio of the population, and males outnumber females indeed.

The age-class distribution observed in our study population shows a pattern typical for chelonian populations (STUBBS *et al.*, 1985, STUBBS & SWINGLAND, 1985; BEN KADDOUR *et al.*, 2006), including other studied *T. graeca* populations (BRAZA *et al.*, 1981; LAMBERT, 1982; ANDREU *et al.*, 2000;

DIAZ-PANIAGUA *et al.*, 2001a,b). Notably, most of the individuals that were collected during the study period (including all seasons) were adults or sub-adults, juveniles being almost inconspicuous. BEN KADDOUR *et al.* (2006) previously reported a similar distribution for the same population in Central Jbilet Mountains. Such a distribution highly biased towards older individuals may be interpreted as an indicator of a low reproductive rate related to severe population dynamic problems such as a lack of generation renewal (STUBBS & SWINGLAND, 1985). BEN KADDOUR *et al.* (2006) suggested that such a pattern could be exacerbated by the very low catchability of juveniles as observed in many reptiles (MADSEN & SHINE, 2000; NAGY, 2000). Juveniles are under strong selection to reach sexual maturity; they remain very cryptic and very hard to find whereas adults exhibit a more conspicuous lifestyle, especially during sexual activities (LAGARDE *et al.*, 2001). Considering the size distribution of animals found dead in the field, BEN KADDOUR *et al.* (2006) confirmed the occurrence of the "missing" juvenile class representing 64% of the total dead tortoises. In the present study, this class was also found, but was much less represented (only 19% of the dead tortoises collected).

We suggest an environmental education plan to minimize all these threats. *Tesudo g. soussensis* is still captured as a pet, despite being illegal. Furthermore, most of the individuals from the Central Jbilet population have been illegally collected. In addition, handling tortoises for research or recreational activities may induce urination (loss of water reserve in the bladder)

due to stress and this can have a negative impact on tortoises during drought periods (ZNARI & HICHAMI, in prep.).

The population size estimate in the central Jbilet Mountains was of 192 adults and sub-adults in spring 2003 (BEN KADDOUR *et al.*, 2006), which corresponds to a population density of about 6 ind./ha. In spring 2012 (the present study), the population size estimate was only 88 adults and subadults corresponding to a halved population density (~3 ind./ha) in less than 10 years. Nevertheless, the estimated tortoise's density is relatively close to those reported in Algeria (~ 4 ind./ha, ROUAG *et al.*, 2007) and Southern Spain (1.7 to 4.2 ind/ha, BRAZA *et al.*, 1981, ANDREU 1987, ANDREU *et al.*, 2000).

All the above-mentioned threats and their combination will cause higher mortality rates and a population decline and extinction.

Stochastic demographic processes might be combined to increase extinction probability in small populations. Also, the number of females is relatively low, which might be imputed to a higher mortality rate in females. If a higher adult female mortality occurs in our population, then we would expect females to be rarer among mature age classes. Our data seem in favor of this hypothesis: females are rare among young individuals. Our results suggest a greater mortality of juveniles and young adult females as causes for the male-biased adult sex ratio, rather than a male-biased hatchling sex ratio. This could be partially corrected by captive breeding and the supplementation of the population with more females than males (VOGT, 1994). Nevertheless, our simulations do

not suggest the release of hatchlings to be a good management measure. In addition, head starting could be a good management tool for long-lived animals, as adult mortality remains very low.

The maintenance of viable populations of the Souss valley tortoise in west-central Morocco is also dependent on an ecological restoration of the population and its natural habitat. Our population viability analysis suggests that the crucial management measures are reducing juvenile mortality and restocking based on a head-starting program. Creating a reserve in this area and talking to local people to convince them to stop collecting tortoises could be helpful. Reducing the effect of chronic drought (especially during summer), could be achieved by constructing drinkers and replanting new jujubes. Supplementing the population with captive-bred and head-started tortoises seems to be a good strategy, but not if the juvenile mortality remains high. However, this activity might have important social effects and could be important for environmental education. Avoiding catastrophes, namely fire, and bush destruction and overgrazing by protecting habitats, is needed to minimize threats. Finally, given the deterministic nature of habitat destruction, measures to correct these problems are a priority. Therefore, we suggest that a project of ecological restoration of steppe-lands is the most important component of the management plan for this population. In Morocco, and as stated before, one of the main bush species in arid areas, the jujube (*Z. lotus*), suffers from officially promoted removal programs. *Testudo g. soussensis* is threatened by such habitat loss. Tortoises are

forced to move between microhabitats looking for essential food resources and thermal refuges (LAGARDE *et al.*, 2012). These authors reported that the occurrence of tortoises is related to that of large and relatively abundant bushes to avoid deathful overheating. Jujube bushes, including the larger ones with tortoises, are over harvested and often cut to the ground and their growth rate is very slow due to the combined effects of regular droughts and overgrazing (LAGARDE *et al.*, 2012). Therefore, the current officially encouraged destruction of jujube bushes need to be substantially limited. Habitat restoration consisting of replanting jujube bush should be favorized. Large-scale monitoring of critical bush densities is necessary for better organizing conservation plans (protection and/or restoration of habitats) for Souss valley tortoise. Finally, construction of small natural reserves, reinforcing and connecting populations through replanting, and a better protection of jujube bushes could considerably improve local habitats in such arid areas.

We concluded that two major factors are deterministic for the long-term persistence of the central Jbilet tortoise population: i) high nest and juvenile mortality, and ii) climatic conditions, especially long drought periods. Therefore, we suggest that *Captive breeding* and *Head-Starting* would be the most significant components of the management plan of this threatened population. In addition, a project of ecological restoration of steppe-lands would enhance the tortoise survival in these degraded and overgrazed arid areas of west-central Morocco.

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