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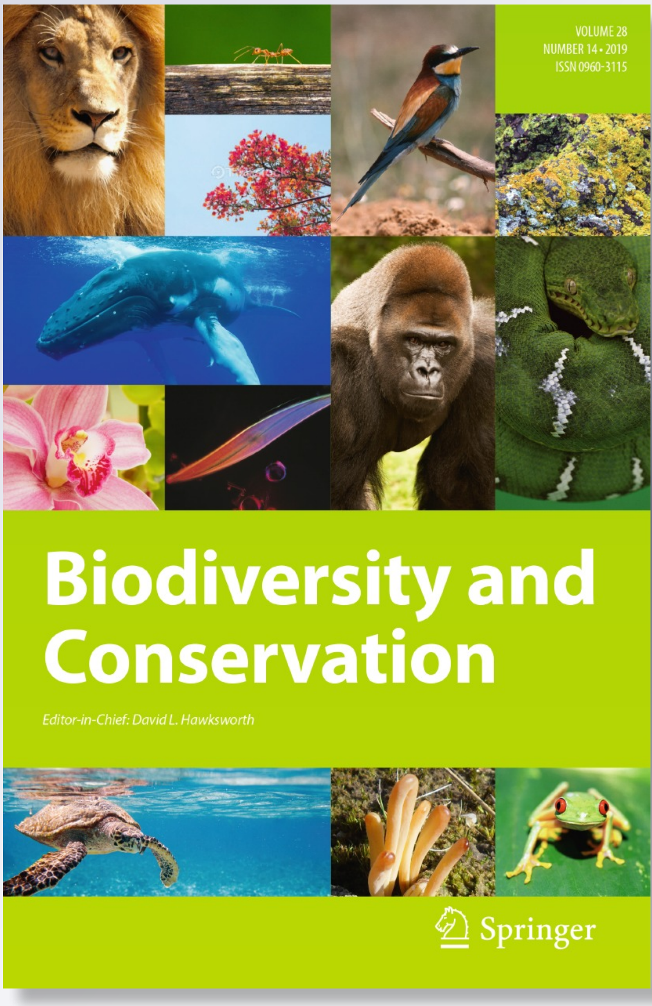

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ORIGINAL PAPER

Excellent performances of dogs to detect cryptic tortoises in Mediterranean scrublands

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Abstract

Mediterranean ecosystems are severely impacted by urbanization, habitat clearing, fires and landscape fragmentation; conservation actions are urgently needed. The protection status of a given area depends notably on the presence and detection rate of protected species. Further, habitat restoration, conservation translocations, or population reinforcement require precise information on the distribution of individuals. Thus, the success of important conservation measures relies on the capacity to locate individuals. Thanks to their sense of smell combined with high learning abilities, dogs have been used to track a wide range of biological targets. They generally surpass humans to detect cryptic species. In this study, we aimed at testing their detection performances with Hermann's tortoises. This secretive reptile provides a typical case of threatened Mediterranean species where protection actions are hampered by low detection rates; especially because low population densities increase the risk of false negative results during surveys. The ability to detect and save individuals, for example before destructive land-work, might be crucial. We evaluated the detection ability of dogs to find tortoises with two experiments. First, field trials showed that relative detection rate was three times higher in dogs compared to well-trained humans. Then, and more importantly, the absolute detection rate of dogs to find radio tracked tortoises was excellent: after two trials, dogs rapidly located all the experimental tortoises dissimulated along different field transects. Overall, dogs were very efficient in finding tortoises, especially well-hidden individuals. More generally, the immense potential of trained dogs should be extended to improve the techniques to detect and protect Mediterranean reptiles.

Keywords Detection effectiveness · Hermann tortoise · Land management · Reptiles · Wildlife detection

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Introduction

Galloping urbanization associated with infrastructure sprawling (e.g. roads, estates, fences) and frequent fires generate an intensive fragmentation of Mediterranean landscapes (Santos et al. 1999; González-Varo et al. 2009; Salvati et al. 2013). Habitat fragmentation severely impacts poorly mobile species with limited distribution range (Meyer et al. 2009). Insufficient dispersal flow can be detrimental to population viability (Fahrig and Merriam 1994). For example, the recovery of populations impacted by strong fires depends on minimal immigration rates (Couturier et al. 2011; Matthews et al. 2016). Consequently, fragmentation combined with habitat loss is catastrophic for species restricted to limited areas and that cannot escape anthropogenic pressures. Creating natural reserves and increasing the surfaces of protected surfaces is a conservation priority for Mediterranean ecosystems (Santos et al. 1999). The presence of strictly protected species offers a powerful means to promote the conservation status of biologically important areas (Quétier and Lavorel 2011; Fraser et al. 2003). Yet, in a rapidly changing environment, this approach might be insufficient to restore the connectivity among populations or to allow individuals to colonize newly available habitats. Translocation is then a valuable tool to alleviate the impact of population isolation due to habitat fragmentation (Terhune et al. 2010). Further, individuals rescued before land-works may supply population restoration or reinforcement programs (Seddon et al. 2014; Germano et al. 2015).

Whatever the strategy, locating individuals with a high efficiency rate is crucial. False negative results may obstruct the classification of a given zone as protected (Cristescu et al. 2015). Regarding translocation, it is essential to find and displace most individuals from the rescue-zone to the host-zone (Germano et al. 2015). However, many organisms are secretive and live in habitats where visual censuses are ineffective; their low detectability represents a recurrent obstacle to perform surveys (MacKenzie 2005). Moreover, in highly threatened species, low densities drastically worsen their detectability (Zylstra et al. 2010; Leigh and Dominick 2015). It is therefore critical to improve detection efficiency, notably for the most discreet species. Logistically demanding techniques should be avoided because intensive and prolonged field work may not be funded on the long-term.

Dogs show a unique set of well-developed characteristics to improve ecological surveys: they display an extremely accurate sense of smell, elevated learning abilities, and a marked willingness to cooperate with humans (Craven et al. 2009; Marchal et al. 2016). They have been successfully used to track a wide range of highly cryptic biological targets: e.g. early-stage diseases (Mc Culloch et al. 2006), bed bugs (*Cimex lectularius*) (Pfiester et al. 2008), nocturnal mammals (Gsell et al. 2010), and different reptiles (Cablk and Heaton 2006; Stevenson et al. 2010; Savidge et al. 2011; Nielsen et al. 2016; Hurt and Smith 2009). For these reasons, dogs have been trained to locate chelonians in the field in USA, South Africa and South East Asia (Platt et al. 2003; Heaton et al. 2008; Mc Cormack 2010; Hudson 2013; Hofmeyr and Henen 2016).

Yet, a key variable, the difference between absolute versus relative detection rates, has been examined in few species and the results revealed important variations (Cablk and Heaton 2006; Kapfer et al. 2012). This difference can have crucial practical implications: quantifying absolute detection rate means that the proportion of individuals that have been found is known, whereas relative detection rates refer to comparison between techniques (e.g. dogs versus men). In this later case, an unknown proportion of individuals (possibly very low) are detected. In other words, only high absolute detection rates can guarantee high detection efficiency during surveys. Further, previous studies comparing the efficiency (number of tortoises located per searching hour) and cost-effectiveness (e.g. including costs of hiring dog teams) of dog versus human surveys provided contrasted outcomes (Nussear et al. 2008; Platt et al. 2003; Boers et al. 2017). Broadly, dogs were particularly useful in dense and closed habitats where visual censuses are ineffective (Platt et al. 2003; Kapfer et al. 2012; Hofmeyr and Henen 2016). Currently, available information is limited however, and thus insufficient to estimate a priori dog's detection rate in other contexts (e.g. dense Mediterranean forests) and in other species (> 98% of the chelonians), and thus to gauge the worth of using dogs.

Most tortoise species are endangered and many inhabit Mediterranean regions (Luiselli et al. 2014; Loehr 2017; Lovich et al. 2018). Habitat fragmentation, repeated forest fires, and mechanical land-works wreaked havoc across populations of the Mediterranean basin, notably those belonging to the *Testudo* genus (Rhodin et al. 2018). In western Europe, tortoises are particularly elusive because they frequently utilize dense shrubby habitats while small individuals remain sheltered most of the time (Livoreil 2009; Ballouard et al. 2013; Couturier et al. 2014; Lecq et al. 2014). Until now, surveys have been performed by humans. Despite intensive field work, detectability remained systematically low (Bertolero et al. 2011; Couturier et al. 2013).

Improving detection rate is urgently needed to cope with increasing urbanization pressure and to better organize land management procedures (e.g. creation and maintenance of firebreaks that can destroy many tortoises) (Ballouard et al. 2013, 2016). Moreover, providing that tortoises can be accurately detected, translocation is an appropriate technique to reinforce populations with rescued individuals (Lecq et al. 2014; Lepeigneul et al. 2014; Pille et al. 2018). Overall, efficient techniques to find free-ranging tortoises are needed. In this study, we precisely tested the performances of trained dogs to detect individuals of a threatened chelonian, the Mediterranean tortoise *Testudo hermanni*. We examined: (1) relative detection rates by comparing the performances of dogs and humans during field surveys, (2) absolute detection rates using radio-tracked tortoises during a field experiment. This study enabled us to assess relative and absolute performances of dogs in detecting Hermann tortoises in dense Mediterranean scrublands.

Material and methods

Study species

The endangered Hermann tortoise (*Testudo hermanni hermanni*; IUCN 2015) is a medium size tortoise with a mean adult body size of 15–18 cm (straight carapace length, SCL) in females and 14–15 cm in males. Historically, the distribution range of this previously abundant species extended throughout a large part of the Mediterranean area from Italy to Spain. The species faces strong population declines, especially in Western Europe. In France, residual populations persist in restricted areas in the Var district and in Corsica (Bertolero et al. 2011; Livoreil 2009). The Hermann tortoise exhibits typical life-history traits of terrestrial chelonians, including long adults lifespan (> 30 years), slow growth rate, delayed maturity (10 to 12 years), low fecundity (3 to 6 eggs), and thus low renewal rate (Bertolero et al. 2011; Arsovski et al. 2018). This species has a generalist diet (herbivorous to omnivorous) and is philopatric (Chelazzi and Francisci 1979). It occurs in plains and hilly landscapes (maximum elevation of ~ 490 m) composed by a mosaic of habitats dominated by Mediterranean scrublands ("maquis"), forests, and abandoned cultures.

Refuges, notably thick shrubs, are essential for Mediterranean tortoises (Lagarde et al. 2012). Most of the shelters used by Hermann tortoises in our study area during the activity season (90%), are composed of dense vegetation, thick herbaceous layer and scrubs (Lecq et al. 2014). Hermann tortoises do not dig their own burrows but sometimes utilize those excavated by other animals (e.g. mammals). Well-buffered shelters (e.g. burrows, cavities, logs) are important during harsh climatic conditions (e.g. freezing or hot temperatures; Bertolero et al. 2011). Individuals tend to shift among refuges every day during the active season; and therefore rely on a wide network of shelters (Hailey 1989; Pille et al. 2018).

The strictly protected Hermann tortoise is considered as an umbrella species (Roberge and Angelstam 2004; Bertolero et al. 2011). Indeed, to limit accidental mortality, state regulations require locating and displacing all individuals before destructive land work (e.g. firebreak maintenance, road construction). This status does not translate into applicable measures however, merely because there is no method to ensure that most (all) individuals can be actually detected in the field.

Currently, standard visual surveys performed by trained people are officially prescribed to assess the presence of the species. However, at least 10 repeated surveys based on capture-mark-recaptures are necessary to obtain robust estimates of individual detection probability for a given searching effort; and these estimates show that despite intensive surveys many tortoises are missed (Couturier et al. 2013). In practice, intensive repeated standard surveys require important logistics, prolonged investigations, and thus are not tractable in most cases. In addition, this method is inefficient to detect small (young) individuals, and is sensitive to observer bias (Freilich and LaRue 1998; Ballouard et al. 2013, 2016). Overall, human-based visual monitoring may not be appropriate to insure a high absolute detection rate in order to (1) promote the conservation status of threatened habitats, (2) to withdraw almost all individuals in the front of land works as requested by state regulations.

Dog teams and training

Table 1 summarizes the composition of the five dog teams (one or two dogs with one handler per team). Six dogs and three handlers participated to the study. The dogs were selected and trained for their ability to detect tortoises without harming them. In order to not perturb wild tortoises, empty shells and captive Hermann tortoises were used during preliminary tests or during exercise sessions. Training tortoises were taken from a pool

Table 1 Dog teams and training

Team	Handler	Dog's name (sex)	Breed pattern	Age	Searching	Experience
1	Fabien	Gaia (F)	Irish setters	6	Hunting	High
2	Fabien	Diva (F)	Brittany spaniel	5	Hunting	No
3	Raphael	Smartie (F)	Brittany spaniel	10	Hunting	High
		Caline (F)	Irish setter	6	Hunting	High
4	Raphael	Joy (F)	Munster spaniel	2	Truffle	Medium
5	Jean-Marie	Hector (M)	Australian shepard	4	Truffle	High

Dogs were classified depending on their searching style, hunting or truffle dogs, and according to their experience (cf. "Materials and methods"). Team #3, two dogs and one handler, participated only to the first experience. The number of dog(s) and human prospector(s) was the balanced for a given trial (see text for details) of individuals accommodated in the SOPTOM rescue centre (district 83, France). These tortoises originated from various sources (e.g. abandoned by private owners, seized from illegal market, born in captivity). They could not be released and they were maintained in semi-natural enclosures (20–50 m^2). Preliminary tests and first training steps were performed in dedicated enclosures (100 m^2): each dog was notably checked regarding potential harming behaviours such as taking a tortoise in its jaws, and received adequate education when necessary.

We classified the searching mode displayed by the dogs either as 'hunting searching style', either as 'truffle searching style'. Hunting searching dogs (e.g. pointers) have an innate ability to search for game animals. They rapidly learned to search specifically tortoises. They didn't receive specific training (except if they exhibited harming behaviour). They rely on air scenting, cover large land surfaces, and exhibit pointing alert when an animal is detected. When out of sight (e.g. 100 m), a signal triggered by the absence of movement is send to the handler by a remote-control training collar (Dogtra RB1000). Truffle searching dogs (Munster spaniel and Australian shepard) search in the close vicinity of the handler (max 10 m away) and maintain their nose close to the ground. They received a specific training to develop their detection ability and motivation for tortoise searching. Shells were presented to the dogs in order to induce sniffing behaviours. Then we placed a shell in the field and allowed the dog to roam around. When the dog found and manifested interest to the shell, it was rewarded with food or hugs. We first placed the shell 3 m away from the dog (random direction) and progressively increased the distance during training sessions. We then replaced the shells with living tortoises (captive individuals). The dogs were also trained to display sitting and barking alert signals when they located a tortoise (Cablk and Heaton 2006). According to age and training experience, we classified the dogs as not, moderately, or highly experienced to detect tortoises (Table 1). Dogs were trained with captive tortoises and thus were not familiar with wild individuals.

Study sites, experimental zones and habitat

Following training, we examined the ability of the dogs to find wild tortoises in natural conditions. We performed the experiments on 10 sites: 7 for the comparison between dogs and humans, and 3 to assess the absolute performances of the dogs, in one site both types of experiments were performed (Table 2; Fig. 1). All the sites were situated in the main core of the distribution of the species, population density estimates ranging from 1 to 10 individual(s)/hectare (Livoreil 2009). The sites were selected to reflect the landscapes used by the Hermann tortoise in France. Most were protected under different legislation requirement (from natural reserve, Natura 2000 network or administrative decrees). The whole surface of each study sites was variable (7–5270 ha); thus we restrained the experiments to standard sub-surfaces according to the two questions addressed:

1. Plots of 5 ha were designed to assess relative detection: one to six plot(s) were delimited and surveyed in each of the 7 study sites (N = 18 plots). The surface covered in each site differed consequently (5–30 ha), and a total of 90 ha were surveyed.
2. Transects of ~ 500 m (see "Results" for details) were designed to assess absolute detection: one or two transect(s) were delimited and surveyed in 4 different sites.

The main habitat type was quite homogeneous across the study sites. It was relatively close with ligneous vegetation covering more than 50% of the ground surface. This

Table 2 Summary of the sites, plots (5 ha), teams and scores used to compare the relative efficiency (Relative detection trials, top table) of dogs and humans, and to assess the absolute efficiency of dogs (Absolute detection trials, down table), to find free-ranging tortoises

Relative detection trials

Site	Plot	Vegetation density	Number of trials	Dog team	Dog score	Human score
Balançan	A	High	1	3	2	1
	B	Medium	1	3	7	1
Fréjus	A	Medium	1	1	2	0
	B	Medium	6	1*(5), 2	25	1
	C	High	4	1*(3), 2	14	4
	D	High	1	1	0	0
Lambert	A	Medium	1	3*	1	1
	B	High	1	3*	2	2
Redon	A	Medium	3	3, 4*, 5*	4	6
	B	Medium	1	4*	3	3
	C	High	1	4	1	0
	D	Medium	1	4*	6	2
	E	High	1	5*	3	2
Roquebrunes	A	High	1	3	1	0
Vidauban	A	Medium	1	3	4	2
	B	Medium	1	3	3	2
Callas	A	High	1	3	4	1
	B	Medium	1	3	4	2
Total	18		28	5	86	30

Absolute detection trials

Site	Transect	Habitat density	Number of trials	Dog team	Dog score (%)	Tracked tortoises
Frejus	A	High	1 + 1	1	66–100	3
Pardiguière	A	Medium	1	1	100	5
			1 + 1	4*	80–100	4
			1	5*	100	5
Maures National Reserve	A	Medium	1	4*	66	3
	B	Medium	1 + 1	4	75–100	5
Carnoules	A	Medium	1 + 1	1	80–100	5
			1 + 1	4	80–100	5
			1 + 1	5	40–100	5
Total	5		9 + 6	3	76–100	40

Vegetation density (medium = 40 to 70%; high > 70%) was estimated in each plot or transect. The number of trials achieved per plot or per transect is provided. One to three dog teams were involved in each plot or transect (team numbers in Table 1). Asterisk indicates the dogs fitted with a GPS, numbers into brackets indicate the number of trials performed by a dog team in a given plot or transect (+ indicate back trips). Scores provide the number of tortoises sighted in each plot (upper part), or the proportion of radio-tracked tortoises found during transects (lower part, cumulative % of first and backward trips). In plots surveyed repeatedly (e.g. Fréjus B and C) several tortoises were sighted more than once

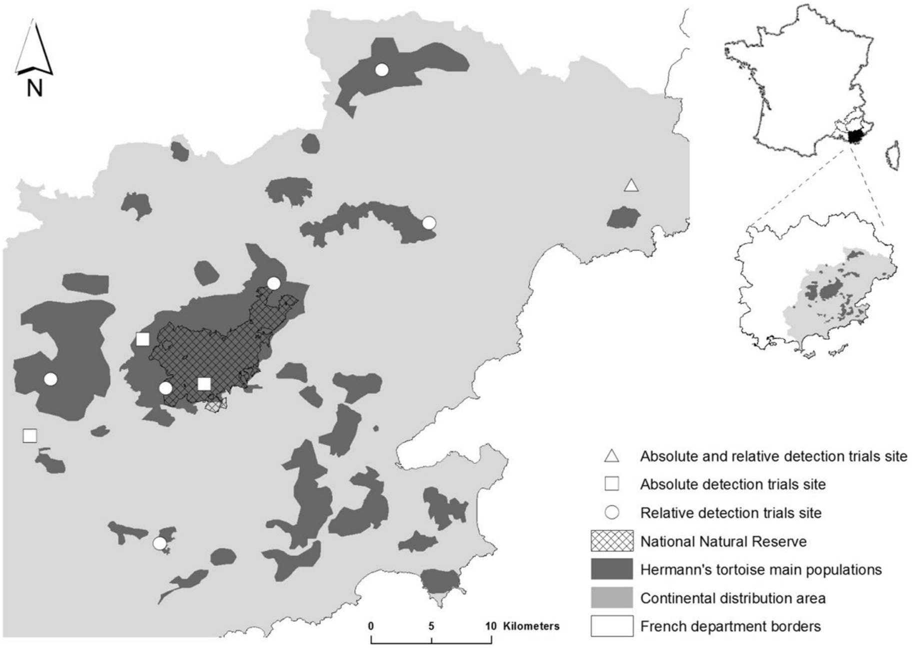

Fig. 1 Map of the 10 study sites. Circles indicate the sites used to assess the relative performances of dogs versus humans to find tortoises (N = 7); squares indicate the sites used to test the absolute performances of dogs to find a known number of radio-tracked tortoises along designated transects (N = 4). On site, indicated with a triangle, was used for both types of experiments

scrubland maquis was composed by thick bushes (e.g. heather shrubs, *Erica arborea*) and forest patches (e.g. *Quercus suber*, *Pinus pinea*). The open zones were composed of herbaceous vegetation with patchy/isolated shrubs (*Paliurus spina-christi*, *Cistus monspeliensis* and *Cistus albidus*). Tortoises are more difficult to find in close and thick vegetation compared to open areas. Vegetation density was therefore visually estimated in each plot or transect: we considered the vegetation density as medium when 40 to 70% of the ground surface was covered by thick shrubs, and as high when this proportion was above 70%.

The Hermann tortoise is the only terrestrial chelonian living in our study area. Wild boars are widespread and their presence may influence dogs during field trials. Humans along with domestic dog frequently visit the study sites. Thus, a variety of olfactory stimuli may distract the dog teams from tortoise searching. These potential perturbing sources were distributed across all the sites and provided a realistic situation for our experiments.

Field procedures

Field trials were achieved under favourable climatic conditions during the activity period of the Hermann tortoise summer excluded (15 April–15 October) (Bertolero et al. 2011). Hottest parts of the year (late June–early September), when tortoises tend to remain sheltered while dogs and humans are rapidly exhausted, were excluded (Smith et al. 2003; Nussear et al. 2008). Surveys were performed in the morning (9:00–13:00), in the absence of strong wind and precipitation, in order to maximize encounter rate (Reed et al. 2011;

Couturier et al. 2013). Previous studies suggested that detection rate may not be affected by wind, ambient temperature or humidity in *Gopherus* tortoises (Cablk and Heaton 2006; Nussear et al. 2008), but current knowledge is insufficient to generalize these results. Precisely, several peculiarities of *Testudo hermanni* (e.g. small body size, moderate reliance on deep burrows, frequent shifts among refuges) make this species prudent in terms of displacements (Moulherat et al. 2014) and thus sighting probability sensitive to climatic conditions (Ballouard et al. 2013).

Relative detection rate of human versus dog

We based the surveys on a standard procedure where human observers visually search tortoises in a 5-ha plot as homogeneously as possible during 60 min (Couturier et al. 2013). Most plots (N = 15 among 18) were surveyed once. Three were surveyed three or six times (sometimes twice by a given team), more than 15 days elapsed between successive surveys in these plots. The total number of trials (i.e. surveys performed one to six times in each of the 18 plots) was 28 (Table 2). The plots were divided into 2 subplots of 2.5 ha. During 30 min, one dog team surveyed a subplot while one human team surveyed the other; during the next 30 min the teams switched subplots and searched again for tortoises. This means that each trial included two sub-trails. Landmarks enabled teams to visualize the subplots assigned. Dogs were deployed off leashed and were guided by voice to keep them within the selected area. Human teams involved one or two people, and in parallel dog teams included one or two dogs. A total of 12 peoples (men or women, handlers excluded) participated, most of them had on average 6-months of experience to locate free-ranging tortoises (range 2 months–5 years). A researcher provided technical support to the dog and human teams: each tortoise found was examined, measured (e.g. body size), marked, localized, and rapidly released at the exact place of capture (Ballouard et al. 2013). Thus, the time required to process the tortoise did not impact searching time (= 30′). In plots surveyed repeatedly (Fréjus, BC, Redon A), several tortoises were recaptured (N = 95 marked individuals). When a tortoise was detected (either by sight or by a dog), a visibility index (proportion of vegetation or substrate concealing the tortoise from sight) was visually estimated by the researcher, in a subsample of 16 plot surveys (N = 63 tortoises).

Absolute detection rate of dogs

We used a known number of radio-tracked tortoises to calculate the proportion of individuals found by dogs along designated transects. In 4 study sites, we fitted 3 to 5 adult wild tortoises (straight carapace length > 15 cm, body mass > 400 g; total number of tortoises used N = 21) with a transmitter (details in Ballouard et al. 2016; Table 3). These tortoises were found during "classical surveys" and were not familiar with dogs or people. Tortoises were located daily, at least during 2 weeks before trials. The day prior to the experiment, the tortoises were located after they had selected a refuge for the night (6 to 8 p.m.). The person who located the tortoises moved randomly around the last location to cover its tracks. The maximal straight distance travelled by a tortoise from the evening location to the next morning was of 4 m. Most tortoises remained hidden in their night shelter (e.g. thick shrub) from 9 to 11 a.m. when the trials were performed. During trials, each dog team surveyed the ground surface along a transect designated by the experimenter who accompanied the dog team without providing any indication about tortoises; thereby mimicking a situation where an unknown number of tortoises should be extirpated from

Table 3 Three responses variables were modelled to assess detection efficiency: named "encounter rates" in the first column

Response variable	Model	Removed variable(s)	P
Comparison dogs vs humans			
Total encounter rate	Veg density + (human vs dogs) + veg density*(human vs dogs)	Veg density* (human vs dogs)	0.43
–	Veg density + (human vs dogs)	Vegetation density	0.08
–	(human vs dogs)	–	< 0.001
Adult encounter rate	Veg density + (human vs dogs) + veg density*(human vs dogs)	Veg density* (human vs dogs)	0.55
–	Veg density + (human vs dogs)	Veg density	0.20
–	(human vs dogs)	–	< 0.001
Juvenile encounter rate	Veg density + (human vs dogs) + veg density*(human vs dogs)	Veg density* (human vs dogs)	0.64
–	Veg density + (human vs dogs)	Veg density	0.12
–	(human vs dogs)	–	< 0.01
Comparison among dogs			
Total encounter rate	Experience	–	0.01
–	Dog type (hunting and truffle searching dogs)	–	0.80

The first is the number of tortoises detected during a 30 min trial, as stipulated line in the methods. The second variable is the probability that a detected turtle was a male versus a female. The third variable is the probability that a detected turtle was an adult versus a juvenile. These last two variables were modeled using raw counts number of males versus number of females; number of adults versus number of juveniles, and following a binomial distribution a known surface, before land works for example (opening firebreaks, etc.). Each transect was set by the experimenter (who was aware of the location of each tortoise) in order to include radio-tracked tortoises (i.e. the route assigned passed approximately 2 to 5 m away from them), but both the handler and the dog were totally naive about tortoise locations. If a radio-tracked tortoise was missed (first run of a trial), a trip back was performed (second run of the trial); thus, each trial may include (or not) a backward trip. A total of 5 transects were used, but two were surveyed by three dog teams (Table 3), thus the total number of trials was 9. Several not radio-tracked tortoises were also found, they could not be taken into account for the calculation of absolute detection rate.

Searching patterns

We fitted several dogs and humans (not the handlers) with a GPS (I got U gt-600) to examine their displacements during trials. Four dogs (2 hunting and 2 truffle searching dogs) and three experienced people were monitored with GPS. The dogs fitted with a GPS and the associated trials are indicated in Table 2. In 12 plots, while comparing the relative detection rates of dogs versus humans, we monitored the displacements of both dog and human teams during 15 trials (2 sub-trials per trial, i.e. 30 sub-trials of 30′ each for dogs and 30 for humans). In 2 transects, while testing the absolute detection rate of the dogs, we monitored the displacements of dogs only during 3 trials. The expected total number of GPS tracks was 63:30 sub-trials for dog teams + 30 sub-trials for human teams in the relative detection tests + 3 trials for dogs in the absolute detection test. Due to several malfunctioning during relative detection tests, we eventually obtained 54 GPS tracks (27 dog and 24 human tracks plus 3 dog trials). One fix was recorded every second. We analysed the total distance and the sinuosity of the tracks. A sinuosity index was calculated, each minute of the track using the ratio between the straight-line distance from the starting point to the last point with successive maximal straight-line distances (path length); 1 indicates a lack of sinuosity, and 0 indicates maximal sinuosity (Benhamou 2004).

Analyses

The number of tortoises detected during a 30 min trial was defined as the encounter rate. We modelled encounter rates using Generalized Linear Mixed Models with Poisson distribution and log-link function. As several trials were performed at the same site, the site ID was used as a random effect in the model. We compared dog versus human efficiency to find tortoises in general, and then considering adult and juvenile tortoises separately. We also tested the effect of vegetation density, searching style (hunting or truffle), and experience on the relative efficiency of prospector (dog or human) by testing the interaction between these factors when appropriate. Finally, we tested whether the dogs and the humans differ in their relative detection ability to find males versus females or adults versus juveniles. We did that by modelling the probability that a detected turtle was a male (versus a female) or an adult (versus a juvenile) using Generalized Linear Mixed Models with binomial distribution and logit-link function (see Table 3 for details). As we modelled abundance in a given plot, or detection probability at the plot scale, and not individual capture histories, the ID of the turtle could not be added as a random factor. All tests were carried out using ANOVA among tested models. Confident intervals of all estimates were obtained through parametric bootstrapping. All analyses were performed under

R environment (R core team 2016) and more specifically using lme4 package for mixed models (Bates et al. 2015).

Results

In total, 178 tortoises were sighted; this number includes 138 different individuals and 40 recaptures (Tables 2, 3). Searching effort and the surface surveyed were greater in the first experiment (during relative detection rate tests: 54 searching hours [28 1-h surveys × 2 teams], 90 ha surveyed) compared to the second experiment (during absolute detection rate tests: N = 62 tortoises; 40 encounters with radio-tracked individuals [N = 21] and 22 others; 12 searching hours and 8.3 ha surveyed). This difference explains why most tortoises were detected during the relative detection assessment (N = 116, 86 found by dogs and 30 by humans, including 20 recaptures).

During the relative detection trials (i.e. people versus dogs) at least one tortoise was found by a dog team in each given plot, except for one trial where no tortoise was detected. Dogs found at least one tortoise in 96% (N = 27) of the trials while people found tortoise in 65% of the trails (N = 18). In one trial, the human team found more tortoises (N = 2) than the dog team (N = 1); in four trials, human and dog teams found the same number of tortoises. Overall, dogs largely surpassed humans to find tortoises in 78% of the trials.

Relative detection rates

Encounter rate was significantly higher ($\chi^2 = 28.2$, df = 1, P < 0.001) in dogs (mean number of individuals detected on the plots = 1.05; 95% CI 0.81–1.37) compared to humans (mean = 0.37; 95% CI 0.25–0.54). On average, dogs detected three times more tortoises per trial than humans. This difference remained significant considering separately adult (dog mean number of individuals detected on the plots = 0.80; 95% CI 0.60–1.07 versus human mean = 0.29; 95% CI 0.19–0.46) or juvenile tortoises (dog mean number of individuals detected on the plots = 0.22; 95% CI 0.17–0.30 versus human mean = 0.06; 95% CI 0.04–0.10). Yet, the probability that a detected turtle was an adult did not differ ($\chi^2 = 0.23$, df = 1, P = 0.63) between dogs (72%, 95% CI 0.60–0.82) and humans (77%, 95% CI 0.57–0.89). Similarly, the probability that a detected turtle was a female did not differ ($\chi^2 = 0.25$, df = 1, P = 0.62) between dogs (66%, 95% CI 0.53–0.80) and humans (60%, 95% CI 0.40–0.77). The interaction between prospector and vegetation density on encounter rates was not significant ($\chi^2 = 0.593$, df = 1, P = 0.43). The experience of the dogs significantly affected encounter rate ($\chi^2 = 8.45$, df = 2, P = 0.01). The difference between hunting and truffle searching dogs was not significant ($\chi^2 = 0.06$, df = 1, P = 0.80).

More than half of the tortoises (53%) found by the dogs were mostly or totally concealed (Fig. 2). The superiority of dogs to locate tortoises increased when tortoises were concealed ($\chi^2 = 10.71$, df = 2, P < 0.001).

The dogs travelled at greater speed, and thus covered greater mean distances than humans (1624 ± 114 m [SD], range 737–3147 m versus 653 ± 41 m, range 310–1114 m) (Fig. 3). The displacements of the dogs were characterized by a greater sinuosity (mean sinuosity index = 0.48 ± 0.02, range 0.27–0.69 in dogs versus 0.76 ± 0.14, range 0.66–0.91 in humans). Hunting searching dogs covered more distance (mean = 1833 ± 170 m, range 737–3447 m) than truffle searching dogs (mean = 1333 ± 70 m, range 987–1735) and they

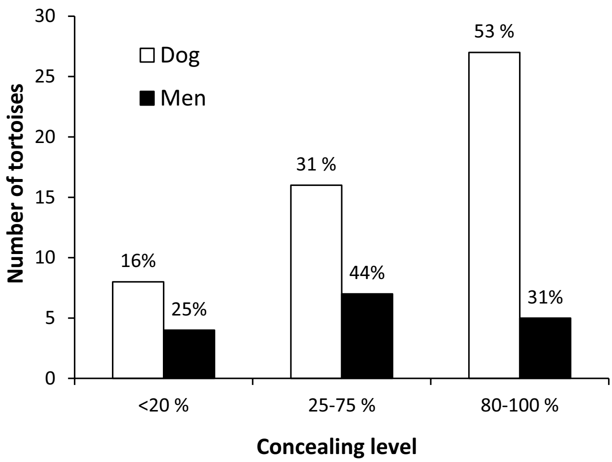

Fig. 2 Proportion of tortoises found by dogs and men according to the concealing level (percentage of vegetation cover on the top the tortoise)

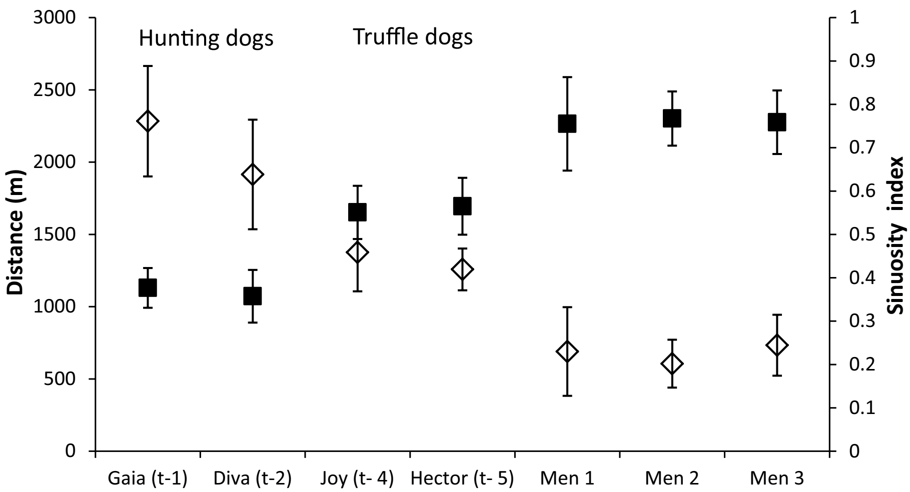

Fig. 3 Mean total distance (white diamond) and mean sinuosity (black squares) of the tracks performed by dogs (total = 27 tracks) and men (24 tracks) monitored with GPS during 30 min trials. Sinuosity index of 0 indicates high sinuosity while 1 indicates low sinuosity. Mean values are presented with SD

displayed a higher mean sinuosity in their trajectories (0.37 ± 0.01, range 0.27–0.43 versus 0.55 ± 0.02, range 0.47–0.66).

Absolute detection

The length of the transects defined by the respective position of the radio-tracked tortoises varied between 283 m and 963 m (520 m on average, Fig. 4). The mean distance between tortoises was 120 m (52 to 220 m). The dogs required 35 min to achieve the shortest trial

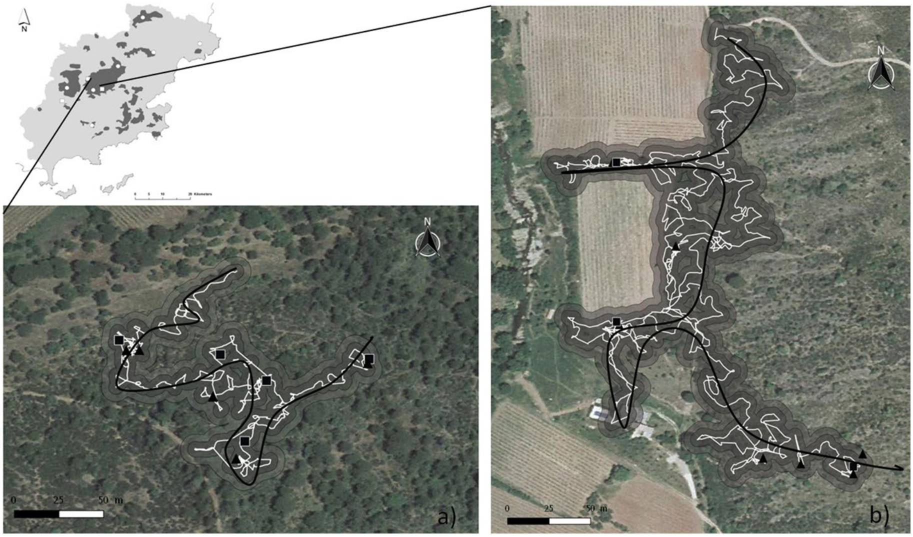

Fig. 4 Examples of two GPS tracks recorded in two dogs (**a** Hector, **b** Joy, see Table 1) during field trials. The dogs searched radio-tracked tortoises along designated transects (black line) defined by the respective position of tortoises (hence they were convoluted) during absolute experimental detection test (**a** Pardiguière, **b** National Natural Reserve, see Table 2). Both handlers and dogs were not aware of the location of the tortoises while searching. Two buffer surfaces along the tracks were drawn according to a detection distance of 5.0 m (dark grey), and then of 10 m (light grey). Black squares represent the respective position of the radio-tracked tortoises and triangles the position of additional not-tracked tortoises found during trials

and 1h34 for the longest; thus, they travelled approximately 600 m in one hour. Yet, in the course of the trials, the dogs moved back and forth to explore bushes; they covered a greater distance than defined by the initial transect (6 times longer; mean = 3432 ± 907 m, range 1751–4863 m; Fig. 4). Considering the sinuosity of the trajectories and a minimum detection distance of 5.0 m (Cablk et al. 2008), the surface patrolled by the dogs was crudely of 1 ha/hp.

All the 40 radio-tracked tortoises were found by the dogs (each tortoise was used more than once). During the first run, the dogs found on average more than 75% of the radio tracked tortoises (40% to 100%, depending upon the dog) (Table 3). All missed tortoises were found during the second run. Twenty-two additional not-tracked tortoises were found by the dogs during trials.

Discussion

Despite growing interest for the use of dogs in wildlife detection (Reed et al. 2011; Woollett et al. 2013; Leigh and Dominick 2015; Orkin et al. 2016), this technique retained the attention of managers in European Mediterranean habitats only recently. In Mediterranean ecosystems that are characterized by a high proportion of endemic and threatened species, almost all surveys are visually performed by human observers, and exceptionally using other techniques like camera-trapping (Ballouard et al. 2016). The current assessment demonstrates that conventional methods based on human surveys might be insufficiently performant considering conservation stakes. The risk of false negative surveys, and of missing individual tortoises before land works, is indeed (very) high. Dogs exhibited excellent absolute rates to detect tortoises, at least adults (75% after one trial and 100% after two trials in the current experiment run under favourable climatic conditions); and on average they found three times more tortoises than humans. This means that the vast majority of the tortoises cannot be visually detected by humans; a result that mirrors the conclusions of previous mark-recapture studies reporting a low probability of detection of free-ranging individuals in this species (Couturier et al. 2013). Although high detectability has been observed in extremely dense populations of the eastern subspecies (Bonnet et al. 2016), the Hermann tortoise is usually a secretive animal that remains often well-sheltered in bushy habitats (Bertolero et al. 2011).

Missing two-thirds of the individuals during surveys may have a catastrophic impact on populations. Indeed, in long-lived organisms, high survival rate is essential for population viability; rescue operations before destructive land works have to collect most individuals. In addition, under low densities the likelihood for false negative surveys is high.

This study demonstrates the potential of dogs to detect cryptic reptiles in a peculiar context. Similar conclusions were obtained in other species in different landscapes; thus, our results further extend the usefulness of dogs to assist peoples during field surveys (Hofmeyr and Henen 2016). Our two sets of experiments were designed to assess both relative and absolute detection rates. The relative detection rates reported confirm that dogs largely surpass humans in dense and complex habitats (Kapfer et al. 2012). The dogs tested were broadly three times more efficient per unit of time (a proxy of searching effort) compared to experienced humans. This value fits well with previous studies in *Gopherus agassizi* or *Terrapene carolina* with efficiency ratio broadly ranging between 2 and 4 (Cablk and Heaton 2006; Heaton et al. 2008; Kapfer et al. 2012). Part of the dog performances relies on their walking speed; dogs covered a distance near to 3 times greater than humans, up to 5 times when searching for desert tortoises (Nussear et al. 2008).

The excellent absolute rate to detect adult tortoises (100% after two trials) is in line with the results obtained (> 90%) in the desert tortoises (*Gopherus agassizii*, a species that lives in open habitats but that also occupies deep burrows) using a similar direct method where radio-tracked individuals were hidden in the field prior trials (Nussear et al. 2008). Our results also support indirect estimates performed with recapture data in the Hermann tortoise: taking into account an individual detection of 8% by humans during 1-h survey in a 5 ha area (Couturier et al. 2013), we can roughly estimate to 24% (dogs are ~ 3 times better) the detection probability using dogs. This crude estimate is in accordance with an absolute detection rate of 100% by dogs searching tortoises in 1 ha during 1 h.

These very high rates may not fully reflect a situation where the exact number and location of tortoises is unknown. In this case, searching would be less oriented (trials were guided along transects in this study while small enclosures were used for desert tortoises in other studies), and the motivation of the dog team may decrease in the absence of reward (Reed et al. 2011). These possible biases cannot be easily tackled however. Fencing tens of hectares with a known number of marked tortoises represent an alternative; but it is technically complex to set up (to prevent immigration and emigration) and logistically extremely expensive. In the current experiment, the dogs and handlers did not know the position of the tortoises that were tracked in their natural habitats; therefore, our results likely reflect a realistic field situation to patrol a designated area.

This study provides potentially useful results regarding the searching effort necessary to effectively survey a given land surface (~ 1 h/ha/dog team; two passes recommended), before habitat destruction for example. To optimize search methods, further investigations are needed however (Glen and Veltman 2018). For instance, testing additional dogs under a greater variety of situations may help to account for possible effects of climatic conditions, dog breed, dog personality, and/or dog team training level. Determining how long a dog can maintain its searching motivation and effectiveness is also important; especially to detect juvenile tortoises that represent the most secretive cohorts, or individuals under very low density. Finding a single small tortoise in 1 ha of complex bushy habitat is challenging situation where the absolute detection rate of dogs should be evaluated. Indeed, following general population collapses, this low density is likely representative of many areas of the current distribution range of the Hermann tortoise in Western Europe (Badiane et al. 2017).

Effective surveys demonstrating the persistence of individuals may contribute to the promotion of the conservation status of large land areas before irremediable anthropization. The strong pressure, exerted by land developers on the habitats where the last populations of Hermann tortoises persist in continental France, is correlated to the extremely elevated price of land in this region (e.g. 100 €/m^2 for non-building land). The classification of more than 5000 ha as a national natural reserve dedicated to the protection of tortoises, in an area intensively coveted by land developers, provides a striking example of the efficiency of the strategy based on the detection of a protected and iconic species (http://www.reserves-naturelles.org/plaine-des-maures).

We did not identify major complications associated with dog surveys (Heaton et al. 2008). Dogs are predators and they possess powerful jaws. Many domestic individuals wander in the study area and they regularly injure or kill tortoises (Gagno et al. 2013). But in none of our trials the dogs attempted to bite the tortoises, and thus likely they represented a minimal nuisance (Boers et al. 2017). Nonetheless, training and carefully selecting dogs is essential to optimize detection efficiency while minimizing logistical investments and nuisances (Boers et al. 2017*)*. Training may also be extended to other reptile species; dogs found two snakes in this experiment while they demonstrated their high ability to locate lizards in other studies (Stevenson et al. 2010; Nielsen et al. 2016; Hurt and Smith 2009).

Recommendations

Hiring a dog team is costly (approximately 100 €/ha), but most of the cost is represented by the salary of the handler (+ logistics). Classical surveys also involve people but are less efficient, and thus can be rapidly expensive. Considering the excellent performances of dogs, the importance of current conservation stakes, and the enormous amounts of funds involved during land transactions and land management, accredited dog-surveys should be implemented as a compulsory technique in official conservation regulations. The main risk associated with such expected changes of official procedures, is that inefficient and/or harmful dog-teams will respond to new market opportunities. A lack of control may have disastrous consequences (Reed et al. 2011; Boers et al. 2017). Therefore, we also strongly suggest imposing a qualification system to accurately test the ability of dog-teams in finding tortoises with limited disturbance for the wildlife. A specific action is currently dedicated to this objective under the framework of the new national action plan devoted for the species (Celse et al. 2018). This study offers solid scientific basis to reach this endeavour and also provides practical recommendations to determine under which frame work dogs should be officially used.

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