The European Turtle-Dove Streptopelia turtur in Northwest Africa: A Review of Current Knowledge and Priorities for Future Research

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Review

THE EUROPEAN TURTLE-DOVE *STREPTOPELIA TURTUR* IN NORTHWEST AFRICA: A REVIEW OF CURRENT KNOWLEDGE AND PRIORITIES FOR FUTURE RESEARCH

LA TÓRTOLA EUROPEA *STREPTOPELIA TURTUR* EN LAS ÁREAS DE CRÍA DEL NOROESTE DE ÁFRICA: UNA REVISIÓN DEL ESTADO ACTUAL DEL CONOCIMIENTO Y PRIORIDADES PARA LA INVESTIGACIÓN FUTURA

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SUMMARY.—In recent decades, a general decline in Palearctic-African migrant birds has been recorded over large areas of the Palearctic. The European Turtle-dove *Streptopelia turtur* has undergone a rapid and serious decline across its European range, to the extent that it was categorised as Vulnerable on the IUCN Red List in 2015. In this review, I synthesise the scientific literature currently available on the Turtle-dove in North Africa *S. t. arenicola*. I also discuss current knowledge, highlight gaps in data and outline high-priority research guidelines, while attempting to direct research efforts more effectively and to encourage appropriate and sustainable management strategies. Priorities for future research are concentrated in five key areas: (i) demography, (ii) migration, (iii) ecology, (iv) genetics, and (v) parasites and diseases. Setting up an integrated programme of long-term ecological monitoring in North African farmland and woodlands, as well as integrating new technologies into monitoring programmes, is an urgent need. These programmes should be standardised in all countries along the migratory flyway to produce comparable data. Scientific collaboration among research institutions, on national, regional and international scales, should be coordinated for maximum efficacy of the monitoring and research programmes.

Key words: agricultural areas, fruit-trees, man-made environment, Morocco, north Africa, *Streptopelia turtur arenicola*.

RESUMEN.—En las últimas décadas se ha registrado un declive generalizado de las aves migratorias paleártico-africanas en grandes áreas del Paleártico. La tórtola europea *Streptopelia turtur* ha sufrido un declive severo y rápido por toda su área de distribución europea, hasta el punto de que se ha categorizado como "Vulnerable" en la lista roja de la UICN en 2015. En esta revisión sintetizo la literatura

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científica actualmente disponible sobre la tórtola europea en el norte de África (*S. t. arenicola*). Discuto también el conocimiento actual, subrayo los vacíos de información y esbozo una guía de las prioridades de investigación que dirijan estos esfuerzos más efectivamente y promuevan estrategias de manejo sustentable apropiadas. Las prioridades de investigación se concentran en cinco áreas clave: (i) demografía, (ii) migración, (iii) ecología, (iv) genética y (v) parásitos y enfermedades. Resulta una necesidad urgente establecer un programa integral de seguimiento a largo plazo en las áreas agrícolas y forestales norteafricanas, así como integrar nuevas tecnologías en ellos. Estos programas deberían estandarizarse en todos los países a lo largo de la ruta migratoria para producir datos comparables. Debería coordinarse una colaboración científica entre instituciones de investigación a escalas nacionales, regionales e internacionales, para una mayor eficacia de los programas de seguimiento e investigación.

Palabras clave: ambiente artificial, árboles frutales, áreas agrícolas, Marruecos, norte de África, *Streptopelia turtur arenicola*.

Introduction

Human activities, from climate change and habitat destruction to overharvesting and the introduction of invasive species, are having a profound impact on the natural world (Parmesan & Yohe, 2003; Halpern *et al*., 2008; Wong & Candolin, 2014). The driving factors of environmental change include deforestation, urban sprawl, transport infrastructures, climate change and the control of water resources by dams, canals and reservoirs (Mclamb, 2009).

Birds have been the focus of intensive research because declines in Palearctic-African migrants have been recorded throughout the Palearctic (Sanderson *et al*., 2006; European Bird Census Council, 2012; Vickery *et al.,* 2014). The effective conservation of this group poses a particular challenge since migratory birds exploit geographically distinct habitats throughout the annual cycle, including different refuelling sites along migratory corridors. Effective conservation plans therefore require coordinated strategies across disparate countries and biogeographic regions.

The European Turtle-dove *Streptopelia turtur* (henceforth 'Turtle-dove') is an example of a Palearctic-African migrant that has undergone rapid and serious decline across its European range (-78% during 1980-2013; PECBMS, 2015). It has been classified as 'Vulnerable' throughout Europe (and 'Near Threatened' within the EU27 countries) following recent assessment (BirdLife International, 2015).

Potential drivers responsible for the species' decline include nesting habitat degradation (Browne *et al.,* 2004), changes in food availability (Browne & Aebischer, 2003) and in wintering grounds, agricultural intensification (Eraud *et al*., 2009), hunting (Boutin & Lutz, 2007), and variation in ecological conditions throughout the migration route (Browne & Aebischer, 2001, Eraud *et al.,* 2009). Turtle-doves in Europe and Northwest Africa are classified as different subspecies: *S. t. turtur* and *S. t. arenicola* respectively (Cramp, 1985). Most research on population decline has focused on the European subspecies and comparatively little is known about the status of the Northwest African subspecies.

In Northwest Africa, Turtle-doves are common migratory breeding birds (Isenmann & Moali, 2000; Thévenot *et al*., 2003; Isenmann *et al*., 2005; Isenmann *et al*., 2016). Morocco holds a large and important Turtle-dove population (Hanane, 2003). Forest areas and fruit plantations represent respectively 12.7% (Mhirit & Blerot, 1999) and 1.5% (MAPM, 2014) of the total land area (TLA) of Morocco. There, although Turtle-doves are widely distributed in forests (Hanane, 2003; Vernon *et al*., 2005, Cherkaoui *et al*., 2007) and agricultural regions (Hanane & Baâmal, 2011; Hanane, 2016a, b), they are more densely concentrated in agricultural landscapes with irrigated areas (2.2% of TLA, MAPM 2014), olive and orange orchards being particularly favoured (Hanane & Baâmal, 2011; Hanane & Besnard, 2014). This proportion is higher than that recorded in Algeria (4.47 10^{-6} % of TLA, FAOSTAT, 2015) and virtually identical to that in Tunisia [2.3% of TAC, FAOSTAT (2015)]. In Morocco, the Turtle-dove is a major game species, highly valued by national and international hunters (HCEFLCD, 2013).

Most studies on both European and Northwest African Turtle-doves have focused on breeding biology (Rocha & Hidalgo, 2002; Browne *et al.,* 2004, 2005; Boukhemza *et al*., 2008; Eraud *et al.,* 2009; Hanane & Baâmal, 2011; Hanane, 2012, 2014, 2015; Brahmia *et al*., 2015; Kafi *et al.,* 2015; Hanane, 2016a, 2016b), breeding habitat use (Browne & Aebisher, 2004; Browne *et al*., 2004; Browne *et al*., 2005; Bakaloudis *et al*., 2009; Dunn & Morris, 2012; Sáenz de Buruaga *et al*., 2012; Dias *et al*., 2013; Yahiaoui *et al*., 2014; Dunn *et al*., 2016), foraging habitat use (Browne & Aebisher, 2003; Dunn *et al*., 2015; Rocha & Quillfeldt, 2015; Gutiérrez-Galán & Alonso, 2016) and migration (Eraud *et al*., 2013; Lormée *et al*., 2016; Marx *et al*., 2016). Both subspecies are granivorous and are true migrants, spending the winter period (late October to late March) mostly in the Sahel region of Africa, south of the Sahara in a broad band spanning the continent roughly between 10°N and 20°N (Browne & Aebischer, 2001). Moreover, both *S. t. turtur* and *S. t. arenicola* nest in forests (Sáenz de Buruaga *et al*., 2012; Dias *et al*., 2013; Yahyaoui *et al*., 2014; Hanane & Yassin, *submitted paper*), fruit orchards (Peiro, 2001; Hanane & Maghnouj, 2005; Hanane, 2009) and hedgerows (Dunn & Morris, 2012; Hanane, 2012).

The goals of this review are twofold. First, I summarise existing literature on the natural history, ecology and status of the Turtle-dove in North Africa. Second, I identify the most important research gaps that need to be addressed to assist the future conservation of *S. t. arenicola*, and propose a framework for developing research and monitoring over the coming years. The proposals will help orient scientific research to address issues of Turtle-dove conservation on both the national and regional scales.

Scientific research on the Turtle-dove in North Africa

In Northwest Africa, 20 peer-reviewed papers have studied the Turtle-dove (Table 1) and have addressed eight topics: nest position within trees, nest density, nest success and habitat, potential competition with other dove species, age-ratio, breeding phenology, the methodological of nest detection and biometry. Of these studies, 70% (n = 14) have involved the Moroccan population and 30% (n = 6) the Algerian population. No studies were found for populations in Tunisia, Libya and Mauritania. I have therefore focused primarily on data from the Moroccan and Algerian Turtle-dove populations in this review. Research in Morocco was mostly conducted in fruit orchards. Only one study has been conducted in a forest habitat.

Current knowledge

Estimation of population size: the case of the Tadla irrigated area

Turtle-doves are a valuable game species in Morocco. Determining the game population size is a basic prerequisite for determining adequate hunting management and conservation strategies and for setting up appropriate hunting quotas. In 2013, a study was conducted in the Tadla region of central Morocco

TABLE 1

Synthesis of published papers on the Turtle-dove *Streptopelia turtur arenicola* in North Africa.
[Síntesis de los artículos publicados sobre la tórtola europea Streptopelia turtur en el norte de África.]

Country	Institution	Habitat types	References
Morocco	Forest Research Center (High Commission for Water, Forests and Desertification Control)	Fruit orchards	El Mastour (1988), Marraha (1992), Hanane (2009a), Hanane (2009b), Hanane (2010), Hanane (2011), Hanane *et al*. (2011), Hanane & Baâmal (2011), Hanane (2012), Hanane (2014), Hanane & Besnard (2014), Hanane (2015), Hanane (2016a, b).
Algeria	National Agronomic Institute of El Harrach, Universities of Guelma and A. Mira	Fruit orchards, forests, and cities	Boukhemza-Zemmouri *et al*. (2008), Belabed *et al*. (2012), Yahiaoui *et al*. (2014), Absi *et al*. (2015), Brahmia *et al*. (2015), Kafi *et al*. (2015).

(Figure 1) to estimate the minimum population size in this area (Hanane & Besnard, 2011). The study was conducted in olive and orange orchards at the peak of the breeding season (from 27 May to 10 June, Hanane & Baâmal, 2011). The authors found that nest density in orange orchards was three times higher than in olive orchards (Hanane & Besnard, 2014) and the size of the breeding population in the Tadla region was estimated to be 58,969 pairs (range 46,281-75,183; Hanane & Besnard, 2014). Olive hedgerows (olive hedge lines) adjacent to crops of cereal (wheat and barley) and forage (alfalfa and corn) promote the settlement of Turtle-doves by providing food in close proximity to their nest sites (Hanane, 2009, 2014). The difference in nest density between orange and olive trees is likely to be driven by the degree of human disturbance. The Turtle-dove breeding period coincides with the presence of fruits in orange orchards, which are highly protected against human intrusions, particularly before the harvests. Such protection is non-existent in olive groves (Hanane & Baâmal, 2011; Hanane & Besnard, 2014) and greater human disturbance in olive groves relative to orange groves may result in lower nest densities.

Although this estimate did not considered belated and precocious breeding pairs, it clearly shows that the Tadla irrigated area is one of the most important breeding grounds for Turtle-doves in the Mediterranean basin. To provide an order of magnitude, the estimate of population size in Tadla is much higher than that for many European countries, including Greece (Snow & Perrins, 1998), Slovenia (Tucker & Heath, 1994) and Cyprus (BirdLife International, 2004), although lower than the overall population sizes reported for Spain and France (Rocha *et al*., 2006; Comolet-Tirman *et al*., 2015). The Tadla data confirms that Morocco is one of the most important breeding areas since it holds high densities of birds, par-

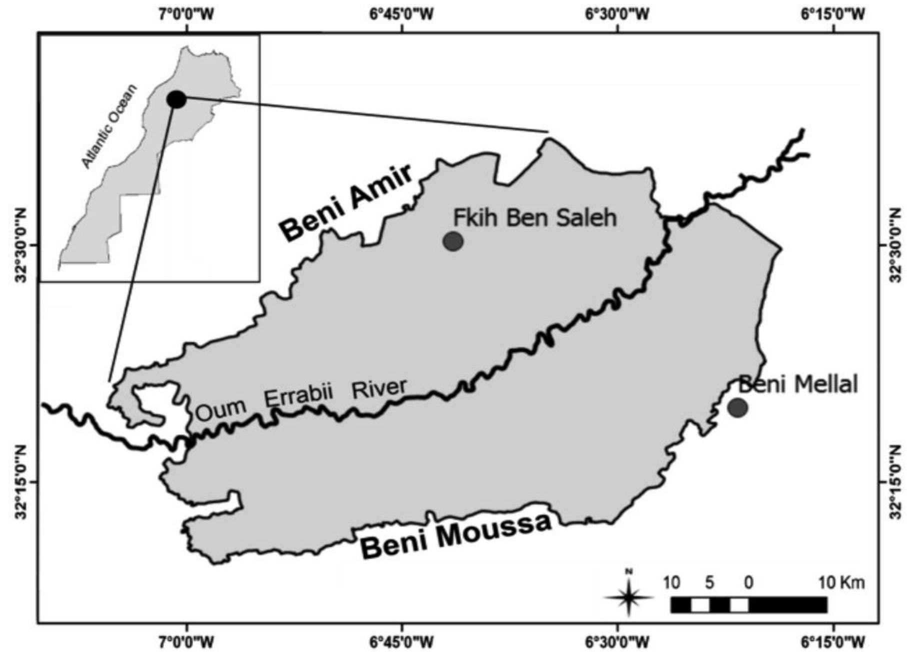

FIG. 1.—The location of the Tadla irrigated area in Morocco (Hanane, 2015).
[Mapa de la localización de la zona de regadíos de Tadla en Marruecos (Hanane, 2015).]

TABLE 2

Turtle-dove nest densities (ha-1) in olive and orange plantations in Morocco and Algeria.
[Densidad de nidos (ha-1) en cultivos de olivos y naranjos en Marruecos y Argelia.]

Country	Irrigated areas	Period	Nests/ha Olive	Nests/ha Orange	References
Morocco	Souss	Breeding season	23	—	Hanane (2014)
	Haouz	Breeding season	28.2	—	Hanane & Maghnouj (2005)
	Tadla	Breeding season	16	45	Hanane & Baâmal (2011)
		Breeding season	10.81 ± 0.30	18.22 ± 0.37	Hanane (2016a)
Algeria	Zéralda + Fréha + Boukhelfa	Breeding season	6.56 ± 3.88	—	Boukhemza-Zemmouri *et al*. (2008)

ticularly since other irrigated areas in the country, such as the Souss valley (Taroudant Region) in the southwest and the Triffa plain (Berkane Region) in the northeast (I. Cherkaoui, pers. comm.), are known to have similar densities of breeding doves (Hanane, 2009). A comparison with nest densities reported in Algerian populations (Table 2) further demonstrates the importance of Moroccan irrigated areas as a high-density nesting zone for African Turtle-doves. In studying the main landscape metrics affecting abundance of game species in a semi-arid agroecosystem in the Mediterranean region, Belda *et al*. (2011) have also reported the great abundance of Turtle-doves in irrigated fruit orchards in Europe.

Occurrence during the annual cycle

Several studies have monitored the timing of spring arrival at irrigated areas throughout Morocco. Turtle-doves arrive earliest in southern Morocco, particularly in the Souss valley irrigated area: in 2009 one at Taroudant on 22 February was followed by birds in the central regions of the Haouz and Tadla: respectively one at Marrakech on 8th March and two at Beni Mellal on 27th March (Hanane, 2009). Regular censuses throughout the season show three important temporal phases in the Turtle-dove breeding cycle (Figure 2): (i) prenuptial migration (March-May) and (ii) postnuptial migration (September-October), in which a somewhat lower number of Turtle-doves were recorded (Fig. 2), and (iii) a stable period (June-August) characterised by a large number of breeding Turtle-doves (Fig. 2) (Hanane, 2009; Hanane & Maghnouj, 2005). A significant difference in the number of Turtle-doves sighted per 4 km transect was also recorded between the three irrigated study areas, with higher densities found in the

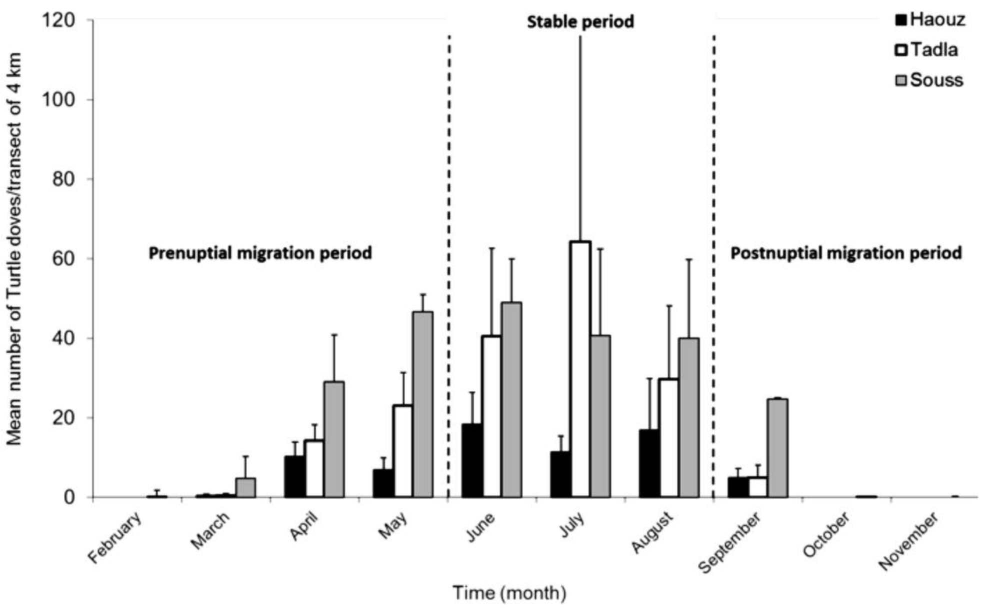

FIG. 2.—Mean number of Turtle-Doves sighted per transect throughout an annual cycle (in 2009) in the Souss, Haouz and Tadla irrigated areas.
[Número medio de tórtolas europeas registradas por transecto durante un ciclo anual (en 2009) en los perímetros irrigados de Souss, Haouz y Tadla.]

Souss and Tadla (94.2 ± 25.9 and 70.9 ± 27.5 respectively) than in Haouz (27.9 ± 9.00) (own unpublished data).

Flexibility in nest placement

Experimental studies in Tadla's irrigated area clearly show non-random patterns of Turtle-dove nest placement (Hanane, 2014). This is confirmed by the existence of optima, which vary according to tree height and type of plantings (Hanane, 2014). However, within this range the species is flexible both in nest placement and the species of tree it nests in, as reported by Hanane & Baâmal (2011), Hanane (2012) and Hanane (2014). This flexibility should favour its persistence in man-made environments.

Nesting success

Determinants of reproductive performance

Until recently, little was known about the factors affecting reproductive parameters of the Turtle-doves in North African agricultural areas. Hanane (2016b) evaluated reproductive performance in relation to location, orchard type, laying period and nest position in Morocco. The results of that study showed that clutch-size was not affected by any of these four covariates, whereas the number of chicks hatched per nest was greater in olive orchards than in orange orchards. In addition, the number of chicks fledged per nest differed with laying period and orchard type, being higher in the early laying period than in the late period, and higher in olive orchards than in orange orchards. During the spring and summer seasons, orange orchards are under continuous agricultural management. Although they are protected as long as orange fruits are still on the trees, they experience extensive disturbance once the orange harvest begins. This is not the case for the olive orchards, which are managed only sporadically. These human disturbances may make orange orchards less desirable as nest sites, especially after the beginning of the harvests, and may result in lower reproductive success. Nonetheless, by considering previous studies carried out in fruit orchards (Hanane & Baâmal, 2011; Hanane & Besnard, 2014; Hanane 2016a) our results are somewhat equivocal due particularly to differences in the timing of the study period (i.e. whether covering the whole breeding season or the peak breeding period).

Neither location nor nest position were related to variation in Turtle-dove fledging success in Morocco (Hanane, 2016b). However, a recent study carried out in orange orchards in Guelma, Algeria, found that the number of chicks fledged per nest was associated with nest height and nest-to-trunk distance as well as the distance to the nearest cereal crop (Kafi *et al*., 2015). The number of chicks fledged per nest was higher in close proximity to cereal crops, and decreased gradually as the distance to the nearest cereal crop increased. This result reinforces the finding that the selection of nest-trees near cereals is beneficial for Turtle-doves (see also Browne & Aebischer, 2003, 2004; Dias *et al*., 2013 and Dunn *et al*., 2016).

Causes of nest loss

Previous studies of Turtle-dove nests in the Moroccan Haouz (n = 180) and Tadla (n = 137) irrigated zones (Hanane & Maghnouj, 2005; Hanane & Baâmal, 2011) found that 130 (41%) were successful in fledging young (Hanane, 2016b).

In Morocco (Hanane & Maghnouj, 2005; Hanane & Baâmal, 2011) as in Algeria (Boukhemza *et al*., 2008), more than half of nest failures were attributed to desertion. These high rates of desertion are probably driven by human disturbance associated with agricultural practices, such as fruit picking, tree pruning, application of pesticides and herbicides and ploughing between the lines of fruit trees), but also involve young people who continuously look for nests during the summer holidays (Hanane & Baamal, 2011; Hanane, 2016a, b).

Coexistence with other dove species: the case of the Laughing Dove

The Laughing Dove *Spilopelia senegalensis* also breeds in Morocco (Thévenot *et al*., 2003; Hanane *et al*., 2011) A study conducted in 2008 and 2009 breeding seasons in the Tadla region (Hanane, 2015) supports the existence of substantial niche segregation in olive nest-trees selected by the Turtle-dove and the Laughing Dove. Niche segregation depends primarily on the proximity of human habitation and cereal crops. Laughing doves nest closer to human habitations and Turtle-doves nest away from humans and in close proximity to cereal crops (Hanane, 2015). The observed nest-niche partitioning may relax competition between these species and enhance opportunities for their coexistence (Hanane, 2015).

Future research directions

Demographic research

Determining spatiotemporal variation in population size is of paramount importance to improving our understanding of the population dynamics of Turtle-doves (Hanane & Besnard, 2014). No information is available on population trends of North African populations. Establishing and maintaining a long-term data collection protocol via a monitoring network has to be the "key priority" for future research programmes. This network should focus on abundance estimation not only within irrigated areas but also in rain-fed farming areas and wooded landscapes. A further advantage in setting up a monitoring network is to determine how Turtle-doves respond to annual climate variability. Assessing the relationship between climatic variables (precipitation, temperature and wind speed) and the presence, abundance, and reproductive success of Turtle-doves is essential to guiding conservation actions and the adoption of appropriate future management.

Finally, a ringing scheme would facilitate estimation of individual survival rates, for understanding and predicting population dynamics. Comparing such rates for North African populations with those estimated for the declining *turtur* subspecies population would be of great importance in identifying the processes that contribute to population declines.

Identification of migration flyways and wintering areas

Knowledge of the migratory patterns of the Northwest African population of *S. t. arenicola* is very limited or non-existent. Many questions remain unanswered, including: (i) what are the main migratory routes of North African Turtle-doves? (ii) where are their major stopover sites? (iii) where are their principal wintering areas? (iv) do North African populations use the same wintering grounds and migratory routes as the European subspecies? If so, to what extent do the two races overlap in habitat and diet? Such questions require research to clarify the Turtle-dove migration system and to develop appropriate conservation strategies.

New technologies, such as light-level geolocators (e.g. Bächler *et al*., 2010; Catry *et al*., 2011; Akesson *et al*., 2012; Bairlein *et al*., 2012; Kristensen *et al*., 2013) and satellite tracking [Geo Location Sensor (GLS), Eraud *et al*., 2013; López-López, 2016; Lormee *et al*., 2016)], are now used for tracking Afro-

Palearctic migratory birds, including Turtle-doves (Eraud *et al.*, 2013; Lormee *et al.*, 2016). Application of these emerging tracking technologies to North African Turtle-doves would help identify their migratory pathways and strategies (Vickery *et al.*, 2014).

Breeding ecology

Nest sites provide the basic needs of breeding adults, eggs and young, including protection from inclement weather (Sadoti, 2008) human disturbance (Hanane *et al.*, 2012; Hanane & Besnard, 2014) and predators (Hatchwell *et al.,* 1999) and offering proximity to food sources (Wiehn & Korpimaki, 1997). Identifying the ecological factors associated with nest site selection in both natural and artificial habitats and at diverse spatial scales: including nest-tree, nest-site, territory and landscape, is therefore important for determining high-priority protected areas. Such information is also useful in assessing the effects of nest predation on the productivity and abundance of Turtle-dove populations.

Regarding survival, it has been noticed that nest desertion is the most important source of reproductive failure for breeding Turtle-doves in Northwest Africa (Hanane & Maghnouj, 2005; Hanane & Baâmal, 2011; Boukhamza *et al.*, 2008). For this reason, it is essential to identify the factors leading to nest desertion within both natural and man-made habitats in order to minimise their impact on breeding success. Three factors contributing to nest desertion are agricultural disruption, hunting and children searching for nests. This last activity overlaps with the breeding season during the latter half of the nesting season period (26.8%). Turtle-doves in orchards are disturbed by several forms of human activity (Mitchell *et al.*, 1996; Hanane & Baâmal, 2011). Agricultural practices (e.g. tillage, grazing, fruit harvesting, tree pruning, application of pesticides and herbicides) are known to impact bird populations directly through mortality or indirectly by modifying food availability and affecting breeding success (O'Connor & Shrubb, 1986; Newton, 2004; Vanbeek *et al.*, 2014; Hanane, 2016a). It would therefore be important to investigate, for instance, how orange orchards constitute an optimal breeding habitat during the first part of the breeding season but thereafter become markedly sub-optimal. Examining the relationship between different types of agricultural habitats and activities and the breeding density, reproductive success and nest desertion rates of Turtle-doves is thus highly important. Since most previous research has focused on irrigated regions, it would be interesting to compare nest density and nesting success in Moroccan agricultural habitats where irrigation is absent.

Hunting

Hunting is a traditional activity that may be compatible with the conservation of biodiversity but that may also threaten biodiversity if sustainable practices are not established (Leopold, 1986; Caro *et al.,* 2015).

Examining the influence of hunting activity on demographic parameters of Turtle-doves in both natural and man-made environments is thus essential to quantifying the impact of hunting on spatial and temporal variation on population size, and to ensure effective management. To collect these data, annual hunting bags should be monitored regularly annually if possible. This will allow the relationship between hunting intensity and population size to be assessed. Analysing the age ratio in hunting bags is also useful for population management, as removal of different age classes can have different effects on population viability (Rocha & Quillfeldt, 2015). Finally, assessing nest desertion rates in regions of heavy vs. light hunting pressure will help determine whether hunting disproportionately affects the population by increasing desertion rates.

Coexistence with other breeding dove species

A recent study (Hanane, 2015) has shown substantial niche segregation in the olive nest-trees selected by Turtle and Laughing Doves, with selection depending primarily on human presence and, to a lesser extent, the vertical distribution of nests.

Complementary studies should also be implemented on feeding ecology, by comparing the food resources consumed by dove species during the breeding season. It would be particularly interesting to investigate whether the diet of these species differs between regions where they breed sympatrically vs. allopatrically. Although research thus far has focused primarily on the Laughing Dove, it could be extended to other ecologically similar species in the community, such as the Namaqua Dove *Oena capensis* (Chevalier *et al*., 2016), Eurasian Collared Dove *Streptopelia decaocto* and Woodpigeon *Columba palumbus*.

Genetic research

The subspecies category was developed to enhance understanding of geographic variation and speciation, and to refine taxonomic distinction (Torstrom *et al*., 2014). Two subspecies of Turtle-doves occur in Northwest Africa, *S. t. arenicola* which breeds in the region and *S. t. turtur* which nests in Europe and crosses the region; two other subspecies are extralimital. However, under the influence of both global changes and anthropogenic landscape modification, it is possible that the distributions of the two local subspecies are shifting. No comparative genetic research has been conducted on the Northwest African or European subspecies (but see, Calderon *et al*., 2016). Using genetic analysis to assess ecological factors such as population connectivity and migration routes would help target conservation efforts on the most important regions.

Parasites and disease research

Recent studies of Turtle-doves in Britain (Lennon *et al*., 2013; Stockdale *et al*., 2015) have shown that the protozoan parasite *Trichomonas gallinae* causes mortality of adults and chicks. For this reason, identifying and studying the sources and prevalence of parasitic diseases is of great importance, not only in North Africa, but in all countries frequented by the Turtle-dove. Comparing the prevalence levels of *T. gallinae* between the two local subspecies would constitute another good way of understanding differences in population dynamics.

Further needs

Coordinating research efforts among countries is recommended to reach the ultimate objective of conserving Turtle-doves. Although a scientific monitoring network focused on migratory birds is well-established in Europe (e.g. http://www.ebcc.info/pecbm.html, French ACT programme, Spanish SACRE programme), no similar network exists in North Africa. Setting up a similar scientific monitoring scheme in this region would benefit not just the Turtle-dove but also other migrant species (e.g. the Common Quail *Coturnix coturnix*) as well as residents (e.g. the Barbary Partridge *Alectoris barbara* and Woodpigeon *Columba palumbus*). Comprehensive data on abundance, habitats, predators, food supplies and climatic influences will help implement an effective management strategy. Moreover, standardising methodological approaches will facilitate broad analysis and implementation of conservation benchmarks across countries.

Conclusions

This review provides a comprehensive synthesis of the current state of knowledge of the Turtle-dove, an important game species in North African intensive farmlands. It highlights priority areas for future research to assist in the conservation of the species. As global climate change and anthropogenic landscape modification progress, scientific vigilance is required to maintain biodiversity. Indeed, there is an urgent need to set up an integrated programme of long-term ecological monitoring in North African farmlands and forests and to apply new technologies to address pressing conservation problems. This approach will enable researchers and policymakers: (i) to assess the importance of different ecosystems for the maintenance of biodiversity, (ii) to identify population trends of species of conservation concern, and (iii) to quantify over time the impact of human disturbance on habitat quality, breeding performance and population size of species of conservation concern. This approach requires the existence, on a national scale, of networks for monitoring Afro-Palearctic migrant bird populations.

Overall, the role of scientific research in providing an evidence base for management actions is of paramount importance. Scientific collaboration among research institutions, both at regional and international scales, is to be encouraged and strengthened in order to share knowledge, skills and techniques.

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