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ECOLOGY OF THE HERMIT BEETLE (*OSMODERMA EREMITA*) IN MEDITERRANEAN WOODLANDS

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Doctoral School in Biology – Section:
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Ecologia del coleottero eremita (*Osmoderma eremita*) in ambienti boschivi del Mediterraneo

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Front cover: a male of hermit beetle (*Osmoderma eremita*) walking on the bark of a cork oak (*Quercus suber*) (Photo by S. Chiari).

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Thesis reviewers:

Glenn Dubois,

Keith N. A. Alexander.

To my family,

my friends,

my love.

‘‘Winter Always Turns to Spring’’

Nichiren Daishonin

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ABSTRACT

One of the most endangered assemblage of species in Europe is represented by saproxylic beetles associated with old trees, as this habitat has decreased severely in Europe during the last 200 years. This thesis contains the first quantitative studies of the population status, the habitat characteristics and the dispersal patterns of *Osmoderma eremita* in Mediterranean woodlands, at the southernmost limit of its distribution range, i.e. central Italy.

Pitfall traps, associated with visual encounter surveys, resulted to be the optimal method to assess the species presence and to obtain reliable population size estimates. Differently from northern Europe, where the demographic structure of this species has been explained by the metapopulation approach, at the southernmost limit of its distribution range a single hollow tree may host only a reduced number of individuals, which do not represent a population in itself, and a single population is widespread on the landscape.

The frequency of presence was higher in cavities with more than 4 l of wood mould, in cavities with dry or half-moist wood mould rather than wet wood mould, and with a low soil contamination. A comparison with northern regions indicated that the warmer macro-climatic conditions in the south made the species independent on sun exposure. As most of the hollow trees contained only a small amount of wood mould (< 4 l), the habitat quality was generally poorer than in the oak pastures studied in northern Europe.

Telemetered beetles spent their life time not only inside hollow trees but also in other habitats, such as on the ground surface and under the ground level. Beetles were more active at the beginning of the season. Even though 81% of the males and 69% of the females conducted dispersals during their life-time, the dispersal distance over individuals' life-time did not differ between sexes. The longest dispersal was conducted by a female that moved 1504 m, and power function predicts that 9.7% of beetles move distances farther than 1600 m. Both dispersal rate and range are higher than what has been found in northern Europe.

Since the population size per tree is low, the habitat quality is generally poor and a high predation rate (at least 28%) was observed in dispersing beetles, conservation efforts for this species should not focus on preserving few and isolated monumental hollow trees, but should be extended to large stands.

PREFACE

This thesis is based on three papers submitted to peer-reviewed journals. In the common introduction were briefly addressed the issues related to saproxylic organisms, to the peculiar characteristics of *Osmoderma eremita* and the overall aims of the thesis. Each one of the following chapters corresponds to one paper, in particular:

CHAPTER 2: Chiari S., Zauli A., Mazziotta A., Luiselli L., Audisio P., Carpaneto G.M. Surveying an endangered saproxylic beetle, *Osmoderma eremita*, in Mediterranean woodlands: a comparison between different capture methods. Submitted.

CHAPTER 3: Chiari S., Carpaneto G.M., Zauli A., Marini L., Audisio P., Ranius T. Habitat of an endangered saproxylic beetle, *Osmoderma eremita*, in Mediterranean woodlands. Submitted.

CHAPTER 4: Chiari S., Carpaneto G.M., Zauli A., Zirpoli G.M., Audisio P., Ranius T. Dispersal patterns of an endangered saproxylic beetle, *Osmoderma eremita*, in Mediterranean woodlands. Submitted.

In the final section, the outcomings of these papers were utilized for drawing conclusions on the status of knowledge on *Osmoderma eremita* at the southernmost limit of its distributional range and for discussing the implications for its conservation.

CHAPTER 1

Introduction

1.1 European forests

The natural vegetation in most of Europe is forest, from the Mediterranean evergreen scrub through the deciduous forests of Central and Western Europe to the boreal forests of Fennoscandia (Bengtsson et al. 2000). Many of these forests are now long gone due to human activities and land-use changes (Perlin 1988). Some European forest types belong to the most severely disturbed and endangered ecosystems of the world (Hannah et al. 1995).

Forests support about 65% of the world's terrestrial taxa (World Commission on Forests and Sustainable Development 1999) and have the highest species diversity for many taxonomic groups including birds (Gill 1995), invertebrates (Erwin 1982; Majer et al. 1994) and microbes (Crozier et al. 1999; Torsvik et al. 1990).

Old growth forest could harbour trees in which hollows with wood mould are formed (Ranius et al. 2009). Wood mould is fungi-infested loose material mainly consisting of rotten wood, often with frass and fragments of dead insects (Ranius 2001). Cavities start to develop when trees are about 150–200 years old (Ranius and Nilsson 1997), providing important habitats for a wide range of invertebrates, birds and mammals (Gibbons and Lindenmayer 2002; Kosinski 2006; Ranius et al. 2005). Many insect species are associated with this microhabitat (Jonsell et al. 1998).

The Mediterranean forests of Europe have been altered by human activities for a very long time and practically no pristine forest appears to be left in the region (Bengtsson et al. 2000). Old trees are now scarce and many species dependent on this habitat are today severely threatened, as isolated populations in small unconnected remnants (Harding and Rose 1986; Speight 1989).

1.2 Saproxilic fauna

Saproxylic organisms, i.e. species that are dependent on dead wood or other saproxylic species during at least some part of their life cycle (Speight 1989), constitute a large proportion of the biodiversity in forests (Siitonen 2001). Some saproxylic species are generalists, but

most of them discriminate between different types of wood habitat; for instance, decay stage (Araya 1993), moisture (Dajoz 1980), successional stage of the deadwood (Siitonen and Saaristo 2000), temperature (Kelner-Pillault 1974), tree girth (Siitonen and Saaristo 2000), and sun exposure have been found to be important factors (Ranius and Jansson, 2000; Lindhe and Lindelöw 2004; Berglund et al. 2009).

Saproxylic beetles have been proposed as indicator species of forest integrity (Speight 1989; Nilsson et al. 2001) because they are highly dependent on dead wood, and are therefore particularly sensitive to forest management practices (Siitonen 2001). In Europe, many saproxylic insects are today threatened (Nieto and Alexander 2010), owing to intensive commercial forestry and changed agricultural management practices, which have decreased the amount and quality of dead wood (Davies et al. 2008).Unfortunately, the understanding of population characteristics of saproxylic beetles is poor at its best, and largely based on anecdotal observations (Komonen et al. 2008). Therefore, there is a need for detailed knowledge about the habitat requirements of the saproxylic species of conservation concern.

1.3 *Osmoderma eremita*

Osmoderma eremita (Scopoli, 1763, Coleoptera: Scarabaeidae) is a up to 3 cm-large flying saproxylic beetle, inhabiting hollow trees of European old growth forests. It has a relict distribution in most parts of Western Europe, and Italy is the southernmost limit of its distributional range (Fig. 1). The larvae develop in wood mould and normally they become pupae after 2 years. The adults emerge the following year and fly in summer, since June. Thus, in nature, development normally takes 3 years and adults live up to one month (Ranius et al. 2005). Adult males produce a pheromone, with a characteristic fruity odour, like apricot or peach, to attract females. This pheromone can be used as bait by scientists for sampling the species and also as kairomone by a specialized predator (*Elater ferrugineus*) for finding its prey; moreover it was hypothesized that this pheromone could be exploited also by other saproxylic beetles as a general cue in habitat selection (Svensson et al. 2004).

1.3.1 Population characteristics

The populations structure and abundance of *O. eremita* was mostly studied in Sweden, the northern part of its distribution range, where hollow trees were usually aggregated in stands. A stand was defined as a cluster of hollow oaks within a distance not exceeding 250 m from one tree to the next (Ranius 2000). The 250 m limit was used

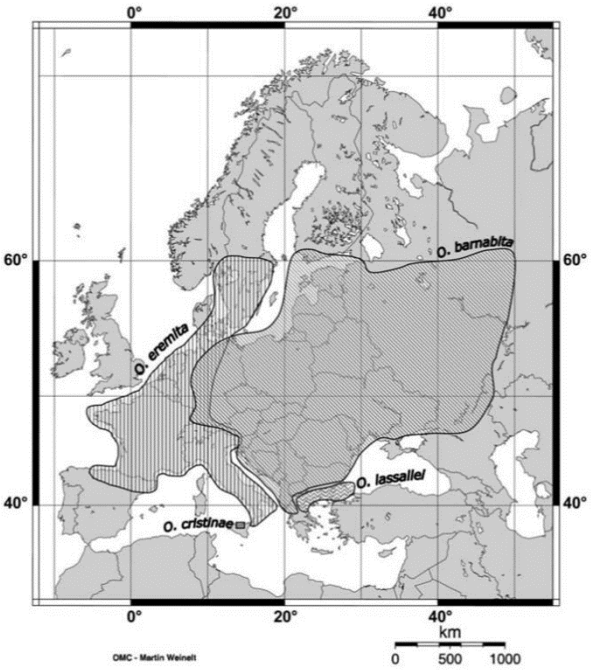

Figure 1 Geographical ranges of the *Osmoderma eremita* complex in Europe (Audisio et al. 2007)

because the first studies on *O. eremita* flight abilities have been found that this beetle has a dispersal distances no further than 200 m (Hedin and Ranius 2002; Ranius and Hedin 2001). Ranius (2000, 2001) showed that *O. eremita* has a metapopulation structure (*sensu* Levins 1969) on a small scale, where each hollow tree is a habitat patch, potentially sustaining a local population. These populations

may be more or less connected by dispersal, and together form a set of metapopulations on a larger scale (Ranius 2000).

In a 5-years mark-recapture study, the population size per tree was found on average 11 adults tree^{-1} year^{-1}, but differed widely between trees (0-85 adults tree^{-1} year^{-1}) (Ranius 2001). The total population size of *O. eremita* in Bjärka-Säby (province of Östergötland, southeastern Sweden) was estimated to be 3900 individuals (Ranius 2001). A following 7-years study case carried out in Bjärka-Säby and Brokind (province of Östergötland, southeastern Sweden) showed that the population estimated in the study sites varied between 1100 and 3400, depending on the capture method, and the population size per tree was found on average from 10.1 adults tree^{-1} year^{-1} to 21.0 adults tree^{-1} year^{-1}, depending on the year (Larsson and Svensson 2009). In the first study case the spatial variability between trees was much greater than temporal variability between years (Ranius 2001), while in the second one the trap catches of *O. eremita* differed dramatically between years (Larsson and Svensson 2009). Carrying capacity was found proportional to the volume of wood mould, generating large differences in local extinction risks between hollow trees, and the habitat dynamics seems to be more important than demographic processes (Ranius 2007). Thus, the *O. eremita* populations were subsequently described in more detail by Ranius (2007), with features from both mainland-island metapopulations (*sensu* Harrison et al. 1988) and habitat-tracking metapopulations (*sensu* Thomas 1994).

1.3.2 Habitat requirements

Generally, beetles living in decomposing wood of late succession stages are not restricted to tree species but to special rot types, microclimate regimes and wood structures (Ranius and Nilsson 1997). Most findings of *O. eremita* have been made in hollow but still living, standing trees belonging to a large range of species (Carpaneto et al. 2010; Dubois et al. 2009; Oleksa et al. 2007; Ranius et al. 2005). As long as there is a suitable tree hollow, it appears that *O. eremita* is rather an opportunistic species with respect to host tree identity, and it should therefore colonize all suitable trees according to their availability. Tree characteristics reflecting suitable microclimate and amount of wood mould have been found to be important at northern latitudes. In Sweden the frequency of *O.*

eremita was found to be higher in hollows with openings directed towards sunny directions (Sud or West) and in warmer stands, as more sun exposed (Ranius and Jansson 2000; Ranius and Nilsson 1997). Also in France the frequency of occurrence was higher in open landscapes (Dubois et al. 2009), indicating that *O. eremita* is rather thermophilic at central and northern latitudes. Furthermore, frequency of occurrence was lower in those tree hollows that contain small amounts of wood mould, which predominantly are younger hollows (Jönsson 2003; Ranius and Jansson 2000; Ranius and Nilsson 1997; Ranius et al. 2009). This means that there is a difference in quality between hollow trees and that the quality, at central and northern latitudes, varies mostly in relation to temperature and to the successional decay stage.

1.3.3 Dispersal abilities

In Sweden, during the first pioneering studies on dispersal abilities of *O. eremita* distances no greater than 200 m were registered for dispersing beetles (Hedin and Ranius 2002; Ranius and Hedin 2001). Following studies concerning the dispersal rate estimate that only 1.6% of the dispersing individuals move distances further than 250 m and most of the adults (82-88%) remained in same tree throughout their life (Hedin et al. 2008; Ranius 2006). Also in the latest studies, carried out at the same latitudes, the species has exhibited a limited dispersal rate and a dispersal distance of up to 300 m (Svensson et al. 2011). A model including all observed individuals yielded a mean dispersal range of 82 m with 1% dispersing more than 1 km (Svensson et al. 2011). In all these studies no significant differences were observed between males and females. The low dispersal rate and distances showed by the species indicated that the populations of each tree have limited connections with each other, and the single stand was found the most relevant scale for *O. eremita* (Ranius 2000).

In France, Dubois and Vignon (2008) reported for one individual a total dispersal of 700 m. In a tethered flight experiment with individuals collected in France, the movements of *O. eremita* ranged from 20 to 1500 m, with a maximum cumulative flight distance of one individual of 2400 m (Dubois et al. 2010). In this study several differences were consistent with sex-biased dispersal in *O. eremita*: flight distance, average and maximum flight speeds were larger in

females. Also, both the take-off and flight completions were different between males and females, and increased in females with lower body conditions, whereas decreased in males (Dubois et al. 2010). The interactions between sex and body conditions on flight capacity may reveal different dispersal strategies between males and females. Moreover, the spatial extent of landscape scale habitat management for this species could be different in relation to different latitudes.

1.3.4 Threats

Among the leading threats affecting *O. eremita* there is the modern forest management which deprives this species of its habitat (Luce 1997). The habitat destruction is mostly due to intensive deforestation for the timber trade, forestry shortened shifts, removal of dying trees or dead trunks, forest fires and changed agricultural management practices (Davies et al. 2008). The replacement of broadleaf trees by coniferous trees supplemented this process of habitat reduction (Tauzin 2005).

Most populations of *O. eremita* inhabit localities which are much smaller, and the genetic effects may have a considerably larger influence on the population viability (Ranius 2001). Therefore, lowered fitness resulting from inbreeding and loss of genetic variation might also increase extinction risks (Ranius 2000).

Due to habitat destruction, habitat alteration and loss of genetic variation, many local extinctions of *O. eremita* are to be expected in the near future (Luce 1997; Ranius et al. 2005).

1.3.5 Status and role in conservation biology

This beetle, protected by the Bern Convention (Appendix 2) and the Habitat Directive (Annex II, IV), is listed in the IUCN Red List of Threatened Species as *near threatened* (Nieto et al. 2009).

In nature conservation working on a single species is important, as it is more likely to be protected by law and it is easier to assess and monitor than groups of species (Caro and O'Doherty 1999; Simberloff 1998). For that reason *O. eremita* was proposed as umbrella species (Ranius 2002). Moreover, this beetle was considered both as an indicator of saproxylic species richness and as a keystone species (Ranius 2002). This may be because *O. eremita* affects the rotten wood habitat both physically and chemically, in a favourable way for other species (Jönsson et al. 2004). Thus, the

preservation of *O. eremita* is important for the survival of the entire invertebrate community associated with hollow trees in Europe (Ranius 2002; Svensson et al. 2003, Ranius et al. 2005).

1.4 Overview of the thesis and aims

A species' ecology may vary within its distribution range, in response to different climatic conditions, or habitat and landscape characteristics (Dover and Settele 2009; Ranius et al. 2011). Moreover, for long-term conservation planning, we need a detailed knowledge about which sites should be given priority, which habitat characteristics should be improved, and how the few suitable trees should be actively managed (Alexander et al. 1996).

In Italy, as in the whole Mediterranean region, knowledge on old trees and saproxylic beetles are still poor. Most of the studies regarding *O. eremita* were carried out in northern and central Europe, first of all Sweden and France, respectively. For most localities with hollow trees in Italy, there are only anectodical information on presence/absence of *O. eremita*, and there are not data at all on abundance. In Mediterranean environments the habitat suitability for *O. eremita* could be different in comparison to the central and northern Europe, and understanding the autecology of the species at low latitudes could enhance conservation efforts and strategies. Finally, the dispersal patterns determine at which spatial scale habitat patch and isolation became critical for long term survival, and should be studied in different ecological and geographical contexts. All these aspects are important for nature conservation, and *O. eremita* could be used as flagship species for conservation in the Italian peninsula, where the status of the few remnaining old forests, and their associated fauna, are very critical.

Therefore, we carried out this work in two of the few areas where *O, eremita* has been found in central Italy (Fig. 2). These areas have been discovered and then selected after preliminary surveys conducted in 2008 for a monitoring project on saproxylic beetles supported by the Regional Park Agency (ARP). The two selected areas appeared the most suitable for *O. eremita* in the Latium region. Until now these areas seem to be the southernmost were the species occurs (Fig. 2).

Figure 2 Italian distribution of *Osmoderma eremita* (modified from CKmap Project, Ministry of the Environment: Ruffo and Stoch 2006). The big dot corresponds to our study areas, including the two new sites discovered during a preliminary survey for ARP in 2008

As no study on *O. eremita* has so far been conducted in the southern part of its range, i.e. in Italy, the overall scope of this thesis is to increase the ecological knowledge on hermit beetle's Mediterranean populations, specifically by pursuing the following aims:

1. testing capture methods to detect the occurrence of *O. eremita* and assessing its population status;

2. describing its habitat requirements;

3. investigating the dispersal patterns of the species.

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PAPER I

CHAPTER 2

Surveying an endangered saproxylic beetle, Osmoderma eremita, in Mediterranean woodlands: a comparison between different capture methods

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Abstract Measuring population size is riddled with difficulties for wildlife biologists and managers, and in the case of rare species, it is sometimes practically impossible to estimate abundance, whereas estimation of occupancy is still possible. Furthermore, obtaining reliable population size estimates is not straightforward, as different sampling techniques can give misleading results. A mark-recapture study of *Osmoderma eremita*, an endangered saproxylic beetle, was performed in central Italy, the southernmost part of its distributional range. Four capture methods were applied on 116 hollow trees to assess their detection probabilities and comparing population size estimates. The modelling approach suggest that there was a strong evidence of detection probability differences among the methods. Despite the use of pheromone and manipulation of the beetles, the capture histories were not affected by phenomena of trap-happiness or trap-shyness. Population size estimates obtained by different capture methods showed variation in abundance and precision. The estimated number of adults per tree, using the whole data set, was 0.5 and 0.2 by closed and open population models, respectively. Pitfall trap was found the optimal method to detect the occurrence of this species. In Italy, a single population of *O. eremita* is widespread on the landscape, and include beetles from more than one hollow tree. Thus, conservation efforts for this species should not focus on preserving few and isolated monumental hollow trees, but should be extended to large stands, especially in the southernmost areas, where local extinction is an imminent risk, and in many cases already occurring.

Keywords Coleoptera Scarabaeidae, Conservation, Dead wood, Occupancy, Population size estimates, Sex pheromone.

Introduction

Estimation of population size is riddled with difficulties for wildlife biologists and managers (Krebs 2009), despite unbiased monitoring of species abundance, in space and time, is crucial to determine extinction risk for threatened species (Schultz and Hammond 2003). Insects and other invertebrates deserve special attention because they are the richest and most diverse group of organisms, whose extinction rate is still largely unknown (Thomas et al. 2004). Trap methods have been widely used for sampling animal populations in the wild, including sampling insects in forest ecosystems (Leather 2005). Trap types used to catch forest insects could be divided into two categories: passive and active traps. A passive trap is assumed be neutral; on the contrary, active traps attract insects by chemical lures, baits, or even colour (Leather 2005). However, the use of passive or attractive traps can make the animals 'trap-shy' or 'trap-happy', thus biasing the assumption of constant probability of trapping success, which is necessary for every trapping survey protocol. Indeed, using passive or attractive traps, the probability of capture tends to decrease with time in some species (Amstrup et al. 2005), or even increase with time for other species (Sutherland 2006).

Saproxylic beetles have been proposed as indicator species of forest integrity (Speight 1989; Nilsson et al. 2001) because they are highly dependent on dead wood, and are therefore particularly sensitive to forest management practices (Siitonen 2001). Unfortunately, the understanding of population characteristics of saproxylic beetles is poor at its best, and largely based on anecdotal observations (Komonen et al. 2008).

Osmoderma eremita (Scopoli, 1763, Coleoptera: Scarabaeidae) is a saproxylic beetle listed in the IUCN Red List of Threatened Species (Nieto et al. 2009) and in the EU Habitats Directive as a priority species of community interest. In nature conservation working on a single species is important, as it is more likely to be protected by law and it is easier to assess and monitor than groups of species (Caro and O'Doherty 1999; Simberloff 1998). For that reason *O. eremita* was proposed as umbrella species (Ranius 2002). However, the populations status of *O. eremita* was mostly studied in Sweden, the northern part of its distribution range, first using passive traps (i.e. pitfall traps) (Ranius 2000, 2001, 2007), then by attractive traps (i.e. pheromone traps) (Larsson and Svensson 2009, 2011). No study on

the population status of this species has so far been conducted in the southern part of its range, i.e. in southern Europe.

Since considerable efforts are devoted to preserve dead wood and the associated insect fauna, quantitative information on population size, structure, and dynamics of forest insects are urgently needed (Komonen et al. 2008). Nevertheless, wildlife management and conservation biology interested in understanding and managing animal population often clash with a lack of rigorous methods for estimating quantities. The general concept of occupancy (i.e., locations where the species is present) is used much more widely than simply in monitoring as a surrogate for abundance (MacKenzie et al. 2006), especially in large-scale monitoring programs (Yoccoz et al. 2001). Sampling programs designed to estimate occupancy tend to require less effort than programs designed to estimate abundance (MacKenzie et al. 2002; Manley et al. 2004; Tyre et al. 2001). In the case of rare species, it is sometimes practically impossible to estimate abundance, whereas estimation of occupancy is still possible (MacKenzie et al. 2004, 2005). Thus, for reasons that include costs and necessity, occupancy is sometimes used as surrogate for abundance.

Therefore, a mark-recapture study of *O. eremita* was performed in central Italy, the southernmost part of its range, using four capture methods to assess their detection probabilities and comparing population size estimates. Explicitly, the following questions were addressed: 1) Are there differences in detection probability between capture methods? 2) Are capture events influenced by trap-happiness or trap-shyness? 3) Are there differences between population size estimates obtained by different capture methods? 4) What is the optimal trap method to detect the occurrence of *O. eremita* in Mediterranean woodlands?

Materials and Methods

Study species

O. eremita is a up to 3 cm-large flying beetle inhabiting hollow trees of European deciduous forests. It has a relict distribution in most parts of Europe, and Italy is the southernmost limit of its range. The larvae develop in wood mould (i.e. loose rotten wood often mixed with fungi, frass and fragments of dead insects) and normally after 2 years they become pupae. The adults emerge the following year and

fly in summer, since June. Thus, development normally takes 3 years and adults live in nature with a maximum of about one month (Ranius et al. 2005). *O. eremita* usually do not overwinter, thus our population estimates should be based on a single cohort of adult beetles. Males produce a pheromone, with a characteristic fruity odour, like apricot or peach, to attract females, and can also be utilized by other saproxylic beetles as kairomone or cue factor in habitat selection (Svensson et al. 2004). *O. eremita* was considered both as an indicator of saproxylic species richness and as a keystone species (Ranius 2002). This may be because *O. eremita* affects the rotten wood habitat both physically and chemically, in a favourable way for other species (Jönsson et al. 2004).

Study area

The study area was Forcella Buana (UTM Zone 33 T, WGS84, 362621 4584425; c. 800 m a.s.l.), an open pasture woodland characterized by an intense livestock-grazing activity, located on Mount Latiglia (southern Latium). Hollow trees were searched systematically through the area and then a subsample (n = 116) was randomly select to set the traps. The subsample size was selected to be able to check the maximum number of traps every day. The study trees were distributed across an area of 25 ha, between 740 and 928 m a.s.l., and belonged to six broad-leaf species: *Ostrya carpinifolia* (n = 93), *Acer obtusatum* (n = 12), *Quercus ilex* (n = 8), *Acer monspessulanum* (n = 1), *Fraxinus ornus* (n = 1), and *Quercus pubescens* (n = 1). Each tree was marked and georeferenced using a Garmin GPS (MAP 60 CSX) (Fig. 1).

Field work

Adult beetles were sampled with three different traps, two actives and one passive. As active traps were used Black Cross Window Traps (BCWT) and Interception Air Traps (IAT), both baited with a neat racemic mixture of γ-decalactone (Sigma-Aldrich, USA). Pheromone dispensers for traps were 2 ml plastic eppendorf vials with cut strings of cotton as wicks, loaded with 1200 µl of the racemic mixture. The BCWT, the same as those used by Svensson and Larsson (2008), consisting of two black plastic sheets (25 cm height×30 cm width, 3 mm thickness) arranged in a cross and attached perpendicular to a plastic funnel (upper diameter 30 cm,

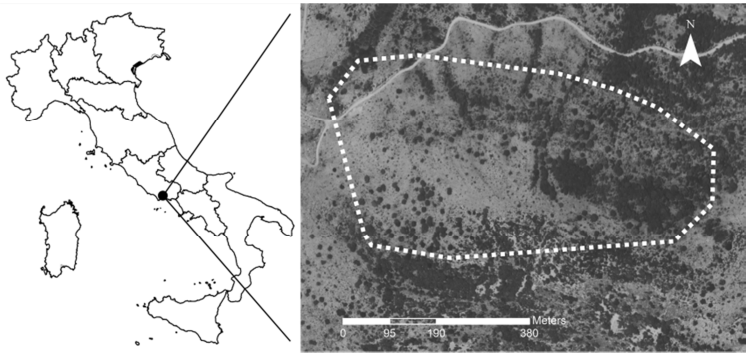

Fig. 1 Overview of the study site, an open pasture woodland located on Mount Latiglia (central Italy), the southernmost limit of *Osmoderma eremita* distributional range. The dashed line delimits the perimeter where sampled hollow trees were located

neck diameter 4 cm) leading down to a 0.5 l white plastic bottle. The IAT traps consisting of a transparent plastic shield (18.5 cm height x 12.5 cm width, 3 mm thickness) with a plastic dust-funnel (upper diameter 12.5 cm, neck diameter 2.8 cm), leading down to a 0.5 l white plastic bottle. The BCWT were placed on the trunk, suspended from tree branches, at the height of the hollow, while the IAT were placed in front of the entrance hole of a cavity. As passive traps were used Pitfall Traps (PT), empty jars placed inside the hollow, with the opening at the level of the wood mould surface (Ranius 2001). PT catch beetles that are walking on the wood mould surface inside the cavities, while IAT and BCWT capture flying beetles outside the cavity.

The traps were set on each tree from the middle of June to the first week of August 2009 and checked every two days. Adults of *O. eremita* were also searched systematically by visual inspection of hollows and trunks; later the catch performed in this way will be mentioned using the abbreviation VES (Visual Encounter Surveys). At first capture each elytron of the beetles was marked by a small drill (Dremel Lithium Cordless 8000JE). No beetle was damaged by the marking procedure. Sex was determined by examining the pronotum; the males has two distinct ridges while the females has only a slight sign of the same convex structure (Hansen 1925). After

the marking procedure, beetles were released in the same hollow tree where they had been captured.

Data analyses

Capture methods

Occupancy models for multiple detection methods permit estimation of occupancy at two spatial scales: the larger scale corresponds to species' use of a sample site (ψ), whereas the smaller scale corresponds to presence of the species at the local sample station (θ). Moreover, this approach permits simultaneous use of data from all methods for inference about method-specific detection probabilities ($\hat{p_T}$) (Nichols et al. 2008). Therefore, first a large-scale occupancy probability (ψ) was explored by condensing detections from each capture method and fitting single species, single season, multi-method model to the *O. eremita* data. Then, the detection probability estimate ($\hat{p}$) was calculated applying the single species, single season, multi-method model separately to each capture method (T). To describe the processes that gave rise to the detection data eight a priori models were considered. Detection probability was modelled as constant over time and detection methods (p), as time-independent but different among methods (p^s), as time-dependent but constant among methods (p_t), or with method as an additive effect with time (p_{s+t}). Models with multiplicative effects of method and time are possible, but were hypothesized to be unnecessary for these data. Small-scale occupancy was modelled as either time-independent (θ) or time-dependent (θ^t). Estimates of θ could reflect a number of influences including range size and movement distances, seasonal and daily activity patterns, or local densities. Models were fit and maximum-likelihood estimates were obtained using the program PRESENCE (Hines and MacKenzie 2004).

Population size estimates

The estimated number of adults, that emerged during the season in the study area, was hereby named as population size. Population size estimates were generated with male and female data pooled. This was necessary given the relatively small sample sizes obtained during the field study. Estimates were calculated using separately information

from each capture method, from each trap method combined with VES, and from all capture methods combined together.

Population size was estimated by capture-recapture data using both closed population models (Craig 1953; Otis et al. 1978) and Cormack-Jolly-Seber open population model method (Jolly 1965; see also Southwood 1978). These alternative methods were used in order to yield a population estimate from different, independent models and hence to make more robust estimates. For the closed population models, the hypothesis of population closure was verified by testing the null hypothesis that the population was not closed. Thus, the proportions of marked individuals for each occasion were ranked and the Pearson correlation coefficient was calculated (Sutherland 2006). Then, the assumption of equal catchability, with the distribution of captures between individuals conforming to a Poisson distribution, was verified by performing the Goodness-Of-Fit (GOF) test (Sutherland 2006).

All the models were built using the program MARK (White and Burnham 1999). The program MARK, for each model, beside the estimate of the parameters, computes the Akaike's Information Criterion corrected for small-size samples (AICc), a measure of goodness of fit of the model combining likelihood and complexity (Burnham and Anderson 2002). The model with the highest support for the capture-recapture data was assumed to be the one with the lowest value of the AICc (Burnham and Anderson 2002).

The coefficient of variation (CV) was calculated as the standard error divided by the number of individuals estimated and indicates the precision of the population size estimate.

The number of adults per tree was calculated using the estimated population sizes obtained (from the whole dataset), for each model.

Trap index

An empirical index was developed in order to rank the different trap methods on the basis of two main aspects: the *Efficacy* and the *Efficiency*, as the probability of detecting the species and the performance of a task in the optimal way possible, respectively. The *Efficacy* ($\hat{p}_T$) corresponded to the results of the occupancy models for multiple detection methods. The *Efficiency* ($\sum_{i=1}^{6} g_i(T)$), according to

Alinvi et al. (2007), was calculated by choosing 6 parameters (i = from 1 to 6) of costs (1 = material costs; 2 = construction time prior the field; 3 = size of the trap, linked to the carriage; 4 = construction time in field; 5 = time to check trap in field and restart the trap; 6 = sensibility to the damage). To each parameter (i), for every trap method (T), a score (g), from 1 to 3 ($1 \leq g_i(T) \leq 3$), was assigned based on experience from the study. The parameters are related to each other and a low score corresponds to high efficiency, i.e. low cost, least time, low sensibility, etc. (Alinvi et al. 2007). To determine which parameters were more important, each one was weighted (w_i = weight) assigning a value between 1 and 4 (1 = minimum weight; 2 = medium low weight; 3 = medium high weight; 4 = maximum weight). High values correspond to high importance, i.e. if a parameter has a value of $w_i = 4$, it is the most important. The Trap Index (TI) for each trap type (T) was calculated as:

$$TI = \frac{\hat{p}_T}{\sum_{i=1}^{6} w_i g_i(T)}$$

The highest score of TI corresponds to the optimal trap method in terms of both *Efficacy* and *Efficiency*.

Results

Mark-recapture

On the whole, 65 captures of 40 individuals (10 males, 30 females) of *O. eremita* were performed (Table 1). Beetles were present in 33% (38/116) of sampled hollow trees. Of 25 recaptures, 12 were carried out in the same tree as the previous capture, whereas 13 took place in a different tree. The female captures outnumbered males captures (P = 0.0002, Fisher's exact test). The longest period elapsed between the first and the last capture was 19 days for males and 17 for females. Of the recaptured males, 50% were recaptured only once, 20% twice and 30% three times. Of the recaptured females, 66% were recaptured only once, 17% twice, 10% three times and 7% four times. The mean time between recaptures was 4.8 days for males and 4.2 days for females.

Table 1 Summary of mark-recapture data obtained during the study of *Osmoderma eremita* in Central Italy with different capture methods (BCWT = Black Cross Window Traps; IAT = Interception Air Traps; PT = Pitfall Traps; VES = Visual Encounter Surveys)

Method	Marked beetles (♂/♀)	Capture events (♂/♀)
BCWT	4/10	4/19
IAT	0/2	0/3
PT	2/17	5/22
VES	4/1	9/3

Capture methods

Estimated large-scale probabilities of occupancy was low ($\psi = 0.29$). Model selection statistics (Table 2) provided a strong evidence that occupancy probabilities were influenced by sampling method (*s*) [summed weights for ψ, θ, p^s model = 0.997]. All the capture methods were consistently poor at detecting *O. eremita* with model-averaged detection probabilities ≤ 0.10 in the top model (Table 3). BCWT and PT performed better [model averaged $\hat{p}_{BCWT} = \hat{p}_{PT} = 0.04$, $SE(\hat{p}_{BCWT}) = SE(\hat{p}_{PT}) = 0.01$] than VES and IAT [model averaged $\hat{p}_{VE} = 0.02$, $SE(\hat{p}_{VE}) = 0.01$; model averaged $\hat{p}_{IAT} = 0.01$, $SE(\hat{p}_{IAT}) = 0.00$] (Table 3).

Population size estimates

The null hypothesis that the population was not closed was rejected (Pearson correlation coefficient: $N = 11$, $r_P = -0.53$, $P < 0.005$). The assumption of equal catchability was accepted (GOF test: $G = 3.50$, $df = 2$, $P > 0.05$).

The population size estimates with closed population models were reported in Table 4, and were similar for the Craig (1953) and the Otis et al. (1978) models. In most cases (6 out of 7) the best-fitting Otis model was M_0 (Table 5), indicating that capture histories were not affected by phenomena of trap-happiness or trap-shyness. Using the Craig (1953) and the M_0 Otis et al. (1978) models the total population size was estimated to be 60 (range = 44-76) and 57 individuals (range = 47-78), respectively. The estimated number of

adults per tree was 0.5 both by Craig (1953) and M_0 Otis et al. (1978) models.

The survey-specific population estimates were different using Cormack-Jolly-Seber model for open populations (Jolly 1965; see also Southwood 1978) (Table 6), and the mean population size was 22 individuals. The considerable differences in the survey-specific population estimates (Fig. 2) suggest that assumption of closed population may not be really solid in this case of study. The estimated number of adults per tree was 0.2 by Cormack-Jolly-Seber model (Jolly 1965; see also Southwood 1978).

Table 2 Summary of model selection statistics for the models of *Osmoderma eremita* capture data during the season 2009. *K* represents the number of parameters in the model and −2Log (*L*) is twice the negative log-likelihood value. Small sample Akaike Information Criteria (AIC*c*) were calculated for each model, conservatively using the number of detection arrays (sample station sites) as the effective sample size (*S* = 116). Relative AIC*c* values and Akaike weight, *w*, are reported for each model (ΔAIC*c* represents the difference in AIC*c* value relative to the top model, Burnham & Anderson 2002). Detection probabilities may vary among method (*s*) or sampling occasion (*t*)

Model	*K*	-2Log (*L*)	ΔAIC_c	*w*
ψ, θ, p^s	6	597.35	0.00	0.997
ψ, θ, p	3	614.99	11.64	0.003
ψ, θ, p_{s+t}	31	568.63	21.28	0.000
ψ, θ_t, p^s	31	569.20	21.85	0.000
ψ, θ, p_t	28	586.42	33.07	0.000
ψ, θ_t, p	28	587.13	33.78	0.000
ψ, θ_t, p_{s+t}	56	564.17	66.82	0.000
ψ, θ_t, p_t	53	582.27	78.92	0.000

Table 3 *Osmoderma eremita* detection probability estimates $\hat{p}$ and associated standard errors (in parenthesis) are given for the multi-method models (w = Akaike's weight for each model)

Model	w	$\hat{p}_{BCWT}$ (SE)	$\hat{p}_{IAT}$ (SE)	$\hat{p}_{PT}$ (SE)	$\hat{p}_{VE}$ (SE)
ψ, θ, p^s	0.997	0.04 (0.01)	0.01 (0.00)	0.04 (0.01)	0.02 (0.01)
ψ, θ, p	0.003	0.03 (0.01)	0.03 (0.01)	0.03 (0.01)	0.03 (0.01)
ψ, θ, p_{s+t}	0.000	0.09* (0.31)	0.02* (0.16)	0.10* (0.31)	0.06* (0.28)
ψ, θ_t, p^s	0.000	0.06 (0.02)	0.01 (0.01)	0.07 (0.02)	0.04 (0.01)
ψ, θ, p_t	0.000	0.08* (0.30)	0.08* (0.30)	0.08* (0.30)	0.08* (0.30)
ψ, θ_t, p	0.000	0.05 (0.01)	0.05 (0.01)	0.05 (0.01)	0.05 (0.01)
ψ, θ_t, p_{s+t}	0.000	0.10* (0.32)	0.03* (0.16)	0.11* (0.32)	0.07* (0.29)
ψ, θ_t, p_t	0.000	0.09* (1.55)	0.09* (1.55)	0.09* (1.55)	0.09* (1.55)

*Parameter estimate reported is the mean value among the 26 detection probability estimates for each detection method
Capture methods names are presented in Table 1

Table 4 Population size estimated by the Craig (1953) and the Otis et al. (1978) models, using captures and recaptures data of *Osmoderma eremita* from different capture methods (ALL = data combined from all capture methods; CV = coefficient of variation)

Capture method	Estimate model	Population size	Confidence intervals (95%)	CV (%)
IAT	Craig			
	Otis			
BCWT	Craig	56	9-103	43
	Otis (M_0)*	47	26-115	42
PT	Craig	168	-50-386	66
	Otis (M_t)*	141	54-485	66
VES	Craig	30	-5-65	60
	Otis (M_0)*	26	13-89	60
IAT+VES	Craig	36	-6-78	60
	Otis (M_0)*	26	15-75	47
BCWT+VES	Craig	55	26-84	27
	Otis (M_0)*	50	35-89	26
PT+VES	Craig	62	31-93	26
	Otis (M_0)*	56	40-98	24
ALL	Craig	60	44-76	14
	Otis (M_0)*	57	47-78	13

*M_0: N, p(.) = c(.);M_t: N, p(t) ≡ c(t). N = population size, p = capture probability, c = capture probability of a marked animal; (.) indicates constant probability and (t) time dependent probability
Capture methods names are presented in Table 1

Table 5 Comparison of the three Otis et al. (1978) models that were used to estimate the population size of *Osmoderma. eremita*. The models for each capture method (ALL = data combined from all capture methods) are ranked by the Akaike's Information Criterion corrected for small-size samples (AIC*c*) (Num. Par. = number of parameters computed; Delta AIC*c* = difference between the models; *w* = model weight; SE = standard error; CV = coefficient of variation)

Capture method	Otis model[a]	Num. Par.	AICc	Delta AICc	*w*	Pop. Size	SE	CV (%)
IAT	M_0							
	M_b							
	M_t							
BCWT	M_0	2	58.831	0.0	0.50	47	20	42
	M_b	3	58.910	0.1	0.48	22	5	24
	M_t	13	64.466	5.6	0.03	44	18	41
PT	M_t	13	35.078	0.0	0.54	141	93	66
	M_b	3	36.039	1.0	0.34	31	6	21
	M_0	2	38.122	3.0	0.12	153	101	66
VES	M_0	2	37.622	0.0	0.74	26	15	60
	M_b	3	39.748	2.1	0.26	34	95	278
	M_t	10	54.773	17.2	0.00	26	15	59
IAT+VES	M_0	2	43.403	0.0	0.74	27	13	47
	M_b	3	45.516	2.1	0.26	25	31	121
	M_t	10	59.039	15.6	0.00	26	12	47
BCWT+VES	M_0	2	70.299	0.0	0.73	50	13	26
	M_b	3	72.235	1.9	0.28	64	66	104
	M_t	10	97.830	27.5	0.00	26	0	0
PT+VES	M_0	2	79.180	0.0	0.59	56	14	24
	M_b	3	79.952	0.8	0.40	38	9	23
	M_t	12	87.889	8.7	0.01	55	13	24
ALL	M_0	2	147.821	0.0	0.48	57	7	13
	M_b	3	148.267	0.4	0.39	47	6	12
	M_t	13	150.381	2.6	0.13	56	7	13

[a] M_0: N, p(.) = c(.);M_t: N, p(t) ≡ c(t); M_b: N, p(.), c(.). N = population size, p = capture probability, c = capture probability of a marked animal; (.) indicates constant probability and (t) time dependent probability

Capture methods names are presented in Table 1

Table 6 Population size estimates of *Osmoderma eremita* derived by applying the Cormack-Jolly-Seber model (Jolly 1965; see also Southwood 1978), using captures and recaptures data from the whole data set (SE = standard error; CV = coefficient of variation)

Control days	Proportion of recaptures	Marked animals in population	Population estimate	SE	CV
1		0			
2	0.25	6	24.0	15.5	65
3	0.50	8	16.0	6.3	40
4	0.33	10	30.0	20.2	67
5	0.50	12	24.0	16.1	67
6	0.63	10	16.5	7.0	42
7	0.29	13	43.8	37.1	85
8	0.33		0.0		
9	0.25	7	28.0	27.3	97
10	0.57	11	19.3	16.8	87
11					
12	0.67				

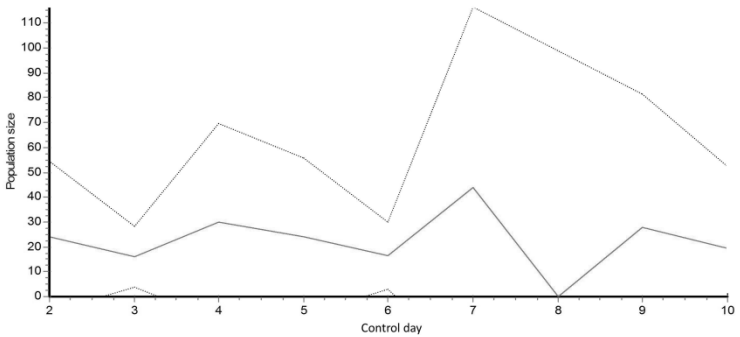

Fig. 2 *Osmoderma eremita* survey-specific population estimates (solid line), from the middle of June to the first week of August, and their 95% confidence intervals (dotted lines) obtained by the Cormack-Jolly-Seber model (Jolly 1965; see also Southwood 1978), using captures and recaptures data from the whole data set

Trap index

The scores (g) for each parameter (i) of *Efficiency* are reported in Table 7. As our study area was located on a mountain with a steep slope, reachable only on foot, in the choice of the trap we were interested in minimizing the size of the trap (i = 3), the construction time in field (i = 4) and the time to check and restart traps in the field (i = 5). To these first three parameters, we assigned the maximum value of weight ($w_3 = w_4 = w_5 = 4$). A relatively high value of weight was assigned to the damage occurred to the traps (i = 6; w_6 = 3). Least importance was assigned to the parameters linked to the costs of materials (i = 1; w_1 = 2) and to the construction time before the field work (i = 2; w_2 = 1). Calculating the Trap Index value for each trap method (TI_T), the ranking was: TI_{PT} = 0.16, TI_{BCWT} = 0.09, TI_{IAT} = 0.02.

Table 7 *Efficiency* measures of the trap methods used in the study of *Osmoderma eremita*. The methods are ranked in relation to each other and the ranking is based on experience from the study. Low rank corresponds to high efficiency, i.e. low cost, short time, low sensibility, etc

Parameters (i)		Trap method (t)		
		BCWT	IAT	PT
1	Material costs	3	2	1
2	Time construction prior the field	2	3	1
3	Dimensions	2	3	1
4	Time construction in field	3	1	2
5	Time to check	3	2	1
6	Sensitivity to damage	1	3	2
	Total	14	14	8

Capture methods names are presented in Table 1

Discussion

Mark-recapture

Osmoderma eremita was present only in a small number of the hollow trees sampled in the study area (38 out of 116), and a maximum of 5 individuals were captured from the same hollow tree. A lower number of captures were registered in comparison to Sweden (Ranius 2000, 2001, 2007; Larsson and Svensson 2009, 2011), where hollow trees are usually aggregated in stands, each with a potential metapopulation (*sensu* Levins 1969) of interconnected local populations occupying individual trees (Ranius 2000, 2007). In our study trap catch of *O. eremita* at a particular hollow tree did not reflect a local population, and the assemblage of hollow trees did not correspond to a metapopulation structure. Thus, a single *O. eremita* population in central Italy is widespread on the landscape, and includes beetles from more than one hollow trees.

Capture methods

The basic occupancy parameter, ψ, corresponds to species occurrence at large scale and was low (0.29). As ψ is an estimate of the probability that a randomly select site of the study area is occupied (MacKenzie et al. 2004), this implies that this beetle species may have some non-negligible probability to be not revealed at the sample unit (hollow tree). Thus, although using a high number of differently designed traps, it is difficult to detect the presence of *O. eremita* in areas where the population is small and widespread on the landscape.

Our modelling approach suggests that there was a strong evidence of detection probability differences among the four detection methods (Table 2). All the capture methods seem poorly reliable in detecting *O. eremita* (Table 3). Probably the low model-averaged detection probabilities (Table 3) are influenced also by the population status of the species, other than the ability of each method in catching beetles. However, the IAT and VES seem to be not reliable methods to assess the presence of the species.

Population size estimates

The population size estimates of *O. eremita*, using the various capture methods, were different to each other and showed a high

variability in their coefficient of variation (Table 4). Despite the use of attractants, the number of captures by IAT was too low and we were not able to calculate the population size with this capture method. Using only captures from the VES method were obtained underestimates of the population size, and using only PT captures were obtained overestimates, respect to estimates calculated from the whole set of data obtained by all methods. According to the precautionary principle in conservation biology, it is better to under- than overestimate the population size (Tikkamäki and Komonen 2011), but the only use of the VES method is not sufficient for a reliable assessment of the population status for *O. eremita*. The overestimates obtained by the PT were probably due to the captures carried out in the last part of the study period, when *O. eremita* showed a reduced flying activity (Chiari et al. unpubl. data) and a tendency to be captured while walking inside the cavities. The influence of time on PT captures, is supported by the best-fitting Otis model for this method, that was M_t (Table 5). Probably, the numerous captures at the end of the study period lead to obtain overestimates with wide confidence intervals as if there was still a large number of beetles to capture. BCWT gave the most reliable estimates of population size in comparison to those obtained with the entire data set, but with a higher coefficient of variation. Population size estimates with BCWT or PT associated with VES are both very similar to those obtained with the entire data set and have a relatively small coefficient of variation. In conclusion, to reach a good assessment of the population status of *O. eremita*, it is enough sampling by BCWT or PT, both associated with VES.

Using the whole data set, the best fitting Otis model was M_0. Even using data from each capture method, and from trap method combined with VES, M_0 was the model that best explained the pattern of capture histories, except for the PT data set (Table 5). Therefore, despite the use of pheromone and manipulation of the beetles, the capture histories were not affected by phenomena of trap-happiness or trap-shyness. The only influence of attractants on the data was revealed by the difference in sex captures (Table 1), that probably reflected the sex-related behavioural differences in response to pheromone, rather than true differences in the number of males and females. In fact, males emit pheromones as a characteristic scent to attract females (Svensson et al. 2009), and the sex ratio for this species should be 1:1, as evidenced by Ranius (2001) in Sweden.

The population size estimates were very different for closed or open population models. Among the closed population models, the Otis et al. (1978) model produced similar estimates with the same coefficient of variation of the Craig (1953) method (Table 4). However, there is a serious risk of overestimating population size using only closed models in our study case, given that estimates done at the level of single surveys were very different among them, as showed by the Cormack-Jolly-Seber model (Fig. 2). Thus, we suggest to use open population models also when the assumption of closure is respected, as precautionary and more conservative way to assess the population status of *O. eremita* in Italy.

Trap index

The PT was the method with the highest trap index score, that best meets both the needs of *Efficacy* and *Efficiency*. The PT method is useful also to assess which hollow tree is selected by the species and therefore probably suitable as nest site. On the contrary, a large sampling effort with BCWT and pheromone results in much higher costs, as well as time consuming and difficult transport and setting. Attractive traps, as BCWT, may indicate the presence of the species in sub-optimal or unsuitable conditions, leading to incorrect conservation actions, as well as increasing the predation risk and reducing the reproductive success of the individuals, becoming local sinks for the population. These risks are consistent especially in the southernmost part of the distributional range of *O. eremita*, where this species shows a low population density, and a high dispersal rate and range (Chiari et al. unpubl. data). We suggest PT as the optimal trap method to detect the occurrence of this species.

Conclusion and implications for insect conservation

This is the first study concerning the population status of *O. eremita* in Italy, and highlights the vulnerability of this species especially at the southernmost limit of its distributional range. In northern Europe, where the demographic structure of *O. eremita* has been explained by the metapopulation approach (Ranius 2000, 2007), the status of the species seems to be more distant from imminent extinction risks. On the contrary, in the southernmost localities, where only a small fraction of hollow trees harbour the species and each one may host only a reduced number of individuals, which do not represent a

population in itself, the imminent risk of local extinctions seems to be very consistent, and probably is already acting.

Monitoring programs to assess the species presence and its population status are urgently needed all over Italy, also as component of larger management processes. Information about method-specific detection probabilities and costs can be used in efforts to optimize study design at large scale. Conservation efforts for this species should focus on preserving, restoring and increasing large stands of hollow trees where the species occurs, especially in the southernmost areas. Otherwise, even though the few monumental hollow trees will be protected, we should expect many local extinctions for this species in the future.

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PAPER II

CHAPTER 3

Habitat of an endangered saproxylic beetle, *Osmoderma eremita*, in Mediterranean woodlands

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Abstract: The habitat of *Osmoderma eremita*, a European endangered beetle species restricted to tree cavities, was examined in central Italy, at the southernmost limit of its distributional range. The occurrence of adults, larvae and fragments was investigated in 151 and 170 living hollow trees by pitfall trapping and sampling wood mould (i.e. loose material) in the hollow, respectively. Overall, *O. eremita* was present in 22% of the trees, which belonged to four different tree species (*Ostrya carpinifolia*, *Quercus suber*, *Acer obtusatum*, and *Quercus pubescens*). The frequency of presence was higher in cavities with more than 4 l of wood mould, in cavities with dry or half-moist wood mould rather than wet wood mould, and with wood mould with a low soil contamination. A comparison with northern regions indicated that the warmer macro-climatic conditions in the south made the species independent on a warm microclimate. As most of the hollow trees contained only a small amount of wood mould (< 4 l), the habitat quality was generally poorer than in oak pastures studied in northern Europe.

Keywords: Coleoptera Scarabaeidae, conservation, hollow trees, microclimate, pitfall traps, wood mould.

Nomenclature: Pignatti, 1982; Löbl & Smetana, 2006.

CHAPTER 3

Introduction

Saproxylic organisms (i.e. species that are dependent on dead wood or other saproxylic species during at least some part of their life cycle) constitute a large proportion of the biodiversity in forests (Siitonen, 2001). Due to habitat loss caused by intensified forestry and agriculture, many of these organisms are now threatened to regional extinction (Nieto & Alexander, 2010). Some saproxylic species are generalists, but most of them discriminate between different types of wood habitat; for instance decay stage, tree girth, tree species, and sun exposure have been found to be important factors (Ranius & Jansson, 2000; Lindhe & Lindelöw, 2004; Berglund, O'Hara & Jonsson, 2009).

In Europe, the area of pasture woodlands has severely decreased during the last century (Harding & Rose, 1986). Pasture woodlands often harbour old broadleaved trees in which hollows with wood mould (i.e. loose material mainly consisting of rotten wood) are formed (Ranius, Niklasson & Berg, 2009). Many saproxylic insect species are associated with this microhabitat (Jonsell, Weslien & Ehnström, 1998). Remnant pasture woodlands often contain only a few suitable trees that should be actively managed to maintain the saproxylic fauna (Alexander, Green & Key, 1996). Therefore, there is a need for detailed knowledge about the habitat requirements of saproxylic species that are to be protected.

Osmoderma eremita is a threatened scarab beetle (Nieto *et al.*, 2009) frequently used as an umbrella species and as an indicator of the diversity of other saproxylic organisms (Ranius, 2002). *O. eremita* has been found in a large range of tree species (Ranius *et al.*, 2005; Oleksa, Ulrich & Gawroński, 2007; Dubois *et al.*, 2009; Carpaneto *et al.*, 2010). Tree characteristics reflecting suitable microclimate and amount of habitat have been found to be important at northern latitudes (Ranius & Nilsson, 1997). Due to differences in climatic conditions, or habitat and landscape characteristics, a species' habitat requirements may differ within its distribution range (Dover & Settele, 2009; Ranius, Johansson & Fahrig, 2011). In the Mediterranean regions of Europe, where the climate is drier and warmer, the habitat requirements of hollow-dwelling beetles have rarely been studied (see however Carpaneto *et al.*, 2010). More research on this fauna is therefore needed in the southern part of its range.

The aim of this study was to describe the habitat requirements of *O. eremita* in pasture woodlands in Italy, by identifying predictors of the occurrence per tree. This is the first time the habitat requirements have been described for a saproxylic beetle in Mediterranean pasture woodlands.

Methods

STUDY SITES

The surveyed study sites, Forcella Buana and San Vito, are two of the few remaining sites in Italy with a high density of hollow trees. These sites are situated 3 km apart with agricultural fields between. The sites have different tree composition and density, and are situated at different altitudes.

Forcella Buana (UTM Zone 33 T, WGS84, 362621 4584425) is an open pasture woodland dominated by the hop hornbeam (*Ostrya carpinifolia*), situated about 800 m a.s.l. on Mount Latiglia. This area has been managed as pasture since a long time and is intensively grazed by cattle. San Vito (UTM 33 N, WGS 84, 362804 4584512) is a half-open woodland dominated by cork oak (*Quercus suber*), situated at about 70 m a.s.l. at the foot of Mount San Biagio. The cork oak woodland in San Vito has been managed for cork production for long time but now such activity is almost abandoned and the study site is currently grazed by goats.

We systematically searched through the sites for trees potentially suitable for *O. eremita* (i.e. hollow trees or old trees without cavities but with big fractures in the trunk). We found 300 potentially suitable trees in Forcella Buana (40 ha), and 161 in San Vito (80 ha) (Table I). All trees were mapped using a Garmin GPS (MAP 60 CSX) (Figure1).

TABLE I. Possibly suitable trees (i.e. with hollows or large fractures) and sampled trees in the two study sites (WMS = Wood mould sampling; PT = Pitfall trapping; BOTH = trees sampled by both study methods).

Study Area	Tree species	Possibly suitable trees	Sampled trees		
			WMS	PT	BOTH
Forcella Buana	*Ostrya carpinifolia*	196	91	105	72
	Quercus ilex	46	7	10	4
	Acer obtusatum	36	10	12	8
	Acer monspessulanum	7	2	1	1
	Quercus pubescens	4	1	0	0
	Fraxinus ornus	3	0	1	0
	Unregistered	8	0	2	0
San Vito	*Quercus suber*	155	38	39	30
	Quercus ilex	3	1	0	0
	Quercus pubescens	2	1	0	0
	Quercus frainetto	1	0	0	0

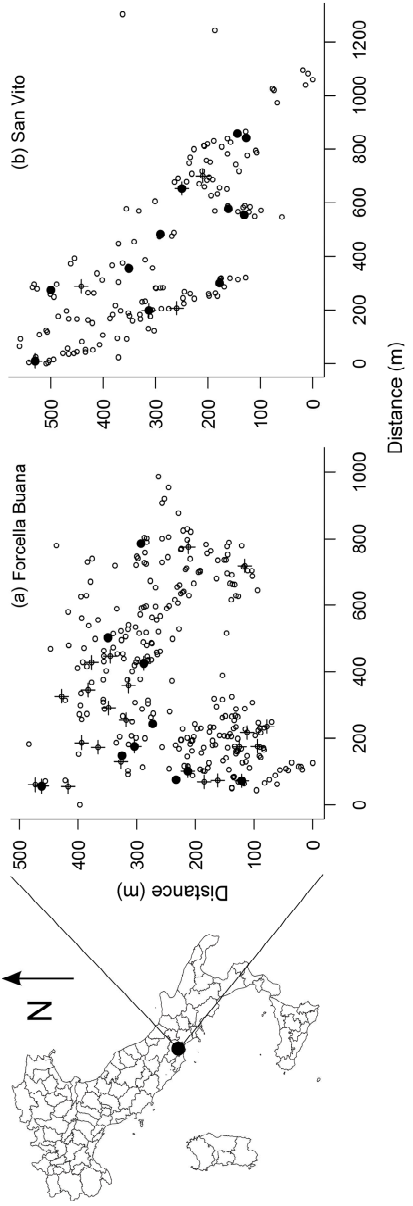

Figure 1. The study sites in central Italy. Open circles indicate trees potentially suitable for *Osmoderma eremita* (i.e. hollow trees or old trees with big fractures in the trunk). The filled circles indicate trees where adult beetles was captured by pitfall traps and the crosses indicate trees where the species was observed by wood mould sampling.

CHAPTER 3

O. EREMITA SAMPLING

Pitfall trapping

We sampled adult beetles in the tree cavities, using pitfall traps consisting of plastic jars placed with the opening at the level of the wood mould surface (Ranius, 2001). Sampling was conducted between the middle of June and the first week of August 2010. The emergence of the adults in central Italy usually starts in the middle of June (Chiari *et al.*, unpubl. data) and the adults have a life time of about one month (Ranius *et al.*, 2005). The traps were checked every two days in Forcella Buana and every day in San Vito. The check frequency differed between the two sites due to the larger number of trees in Forcella Buana. We set one pitfall trap per tree in 131 living hollow trees in Forcella Buana and 39 living hollow trees in San Vito (Table I). Pitfall traps catch beetles that are walking on the wood mould surface inside the cavities, indicating that the tree is selected by the beetles and therefore probably suitable as a reproduction site. Adults were always released after the trap check.

Wood mould sampling

We also detected presence/absence of *O. eremita* by going through wood mould samples taken from the tree cavities. We took samples of wood mould from 111 living hollow trees in Forcella Buana and 40 living hollow trees in San Vito during August 2010 (Table I). In some trees, sampling was impossible because the entrance hole was too narrow or too high (more than 3 m), or the wood mould surface was too deep to reach. Usually, sampling was possible only in one cavity per tree, but if there were more than one cavity we randomly selected one for sampling.

We took up to four 2-litre samples of wood mould from each tree. In 26% of the trees (40 out of 151) the volume of wood mould was ≥ 8 l. The wood mould was sieved and spread out on a white sheet in the field. We examined carefully each 2-litre sample for 15 minutes searching for larvae or fragments (elytra, pronota or heads) of dead adults of *O. eremita*. The larvae were identified according to Klausnitzer (1978). After sieving, the wood mould was returned into the cavity.

EXPLANATORY VARIABLES

We characterized the habitat quality of cavities, trees and landscape by measuring 16 predictors which may affect the occurrence of *O. eremita*, since they reflect microclimate or habitat amount or quality (Table II). Similar variables have been tested in a study of *O. eremita* in northern Europe (Ranius & Nilsson, 1997).

We calculated connectivity by summing the trees hosting *O. eremita* (both from would mould sampling and pitfall traps) within a circle of given radius. We tested the effect of connectivity at different radii (1 m step from 1 to 1000 m) on *O. eremita* presence/absence using a binomial generalized linear model. We then selected the radii at which the model gave the minimum residual deviance.

DATA ANALYSIS

Given that multicollinearity among explanatory variables can hamper identification of the most causal variables, we calculated a correlation matrix of the variables and for every highly correlated pair ($r > 0.65$) only one variable was retained for further analyses (Appendix A). Based on these analyses, we excluded the foliage density to the south and the amount of wood mould due to their correlation with the foliage density over the cavity and the sampled volume of wood mould, respectively. We retained the foliage density over the cavity and the sampled volume of wood mould because they showed a higher explained deviance.

Due to the relatively high number of potential predictors we used multi-model inference within an information-theoretic framework (Burnham & Anderson, 2002) to evaluate the role of the 14 variables retained in explaining the presence of *O. eremita*. Compared to single model inference and traditional null-hypothesis testing, multi-model inference is a better approach in observational explanatory analyses when a single hypothesis is difficult to construct (Johnson & Omland, 2004). As we had no *a priori* hypotheses supporting interactions between the considered explanatory variables we did not include any interaction terms in our model selection procedure.

To evaluate the effect of the variables on presence/absence of the species we used generalized linear mixed-effect models with a binomial error distribution and a logit link function (Quinn & Keough, 2002). Species presence/absence per tree was the dependent variable, site was a random factor and the other variables were the

TABLE II. Measured variables of hollow trees tested as predictors for occurrence of *Osmoderma eremita*.

Name	Description
Amount of Wood Mould (AWM)*	Amount of loose materials in the hollows estimated assuming it had the shape of an inverted cone (Ranius, 2007; l, log transformed)
Moisture (M)	The conditon of wood mould inside the cavity: dry (0), half-moist (1), moist (2), wet with liquid (3)
Proportion Wood Mould/Soil (PWMSo)	The composition of loose material inside the cavity: >75% wood mould (1), 51%-75% wood mould (2), 50% wood mould and soil (3), 51%-75% soil (4), >75% soil (5)
Sampled Amount of Wood Mould (SWM)	Amount of loose material surveyed: up to 2 l (1), 4 l (2), 6 l (3), 8 l (4)
Type of Wood Rot (TWR)	Type of rotten wood in the visible part of the cavity: absent (0), brown (1) or white (2)
Area of Entrance Hole (AEH)	Estimated based on the height and width of the entrance, assuming the form of an ellipse (m^2; log transformed)
Closeness (CLO)	The vertical projection of foliage around the tree: <25% (0), 25%-75% (1), >75% (2)
Direction Sunshine (DS)	The direction of the entrance in relation to the sun: NE = 0; N or E = 1; NW or SE = 2; W or S = 3; SW = 4
Distance to Wood Mould (DWM)	If the vertical distance between the entrance hole and the surface of wood mould was zero (0) or not not (1)
Foliage Density Sun (FDS)*	The percentage of the sky covered by foliage seen from the trunk at the height of the entrance at the angles where the sun is in the summer (arcsen transformed)
Foliage Density Cavity (FDC)	The percentage of the sky covered by foliage seen from the trunk at the height of the hole at the angles from the entrance of the cavity (arcsen transformed)
Height (H)	If the entrance hole was at the ground level (0) or not (1)
Number of Entrance Holes (NEH)	Number of entrance holes per tree
Slant (S)	Slant of the entrance hole in relation to the ground level: 0° (0), 45° (1), 90° (2)
Trunk Diameter (DIAM)	Trunk diameter at 1.3 m height (m; log transformed)
Connectivity (CON)	Numbers of trees with the species present quantified at different radii

* Variables not included into statistical models due to strong correlation with other variables.

independent fixed factors. By including site identity in the model, we took into account that the occupancy may be affected by some unmeasured landscape-scale characteristic. Due to the large number of potential predictors, we performed a preliminary selection of the variables using second-order Akaike's information criterion (AICc) (Sugiura, 1978). The AICc is a measure of relative model fit, proportional to the likelihood of the model and the number of parameters used to generate it. We included each of the 14 explanatory variables in a separate mixed model with site as random factor. If the inclusion of the single variable decreased the AICc value of the null model (i.e. a model including only intercept and site), the variable was further analysed in the multi-model inference analysis.

The variables retained in the procedure described above were further analysed in multivariate models with the following procedure. We compared the fit of all the possible candidate models obtained by the combination of the selected predictors using AICc. The best fitting model is the one with the lowest AICc. In a set of *n* models, each model *i* can be ranked using its difference in AICc score with the best-fitting model ($\Delta AICc_i = AICc_i – AICc$ minimum). A model is usually considered plausible if $\Delta AICc < 2$ (Burnham & Anderson, 2002). For each model *i* we also calculated an Akaike's weight (w_i), which sums to 1 and has a probabilistic interpretation: of all the candidate models, w_i is the probability that model *i* would be selected as the best fitting model if the data were collected again under identical circumstances (Burnham & Anderson, 2002). Akaike's weight should be interpreted as a measure of model selection uncertainty. To evaluate the relative importance of each predictor within our set of models, we summed the w_i values across all models in which the predictor occur (Burnham & Anderson, 2002). The multi-model inference analyses were performed using the 'MuMIn' package (Barton, 2010) implemented in R version 2.8.0 (R Development Core Team, 2011). For all models, we calculated the proportional reduction in deviance as a measure of-goodness-of-fit. The procedure described above was performed for pitfall trapping and wood mould sampling data separately.

Results

FREQUENCY OF OCCURRENCE

Among 170 trees surveyed by pitfall traps, we captured 38 adults in 20 trees (10 in *Q. suber*, 8 in *O. carpinifolia*, and 2 in *A. obtusatum*). By sampling wood mould in 151 trees, we observed 31 species occurrences (21 in *O. carpinifolia*, 5 in *Q. suber*, 4 in *A. obtusatum*, and 1 in *Q. pubescens*). Most of these occurrences were based on observations of larvae (22 of 31), while the remaining observations were based on live (1 of 31) or fragments of dead (8 of 31) adult beetles.

There was a tendency to a positiveassociation between occurrences observed with pitfall trapping and with wood mould sampling, but the relationship was not statistically significant (Fisher Exact Probability Test, P = 0.088) (Figure 1).

MULTI-MODEL INFERENCE

Univariate tests showed positive relationships (reducing AICc) between the occurrence of *O. eremita* detected by pitfall traps and the area of entrance hole, trunk diameter, and number of entrance holes. In the wood mould sampling data, there was positive relationships (reducing AICc) between the occurrence of *O. eremita* and the proportion of wood mould (in relation with soil), sampled volume of wood mould, distance from the entrance hole to the wood mould surface, the height of entrance hole from the ground, and moisture of the wood mould. Connectivity did not reduce in any case the AICc when tested against the null model.

When using pitfall trapping data, multivariate tests resulted in eight plausible (i.e. ΔAICc < 2) models (Table III). The null model was included in the set of plausible models, indicating a generally weak support for the effect of the predictors included in these models. The proportion of explained variation was relatively low (7.6 % by the best model). The area of entrance hole was the most important predictor ($w_{AEH} = 0.58$). The number of entrance holes and trunk diameter had the same sums of model weight ($w_{NEH} = w_{DIAM} = 0.42$).

The models based on wood mould sampling explained a larger proportion of the total variation (21.5 - 28.4%) than the models for pitfall trapping data. The best predictors were moisture ($w_{M} = 0.97$)

and sampled volume of wood mould (w_{SWM} = 0.96). Also the distance from the ground and the proportion of wood mould (in relation with soil) considerably contributed to predict the occurrence of *O. eremita* (w_{H} = 0.73; w_{PWMSo} = 0.69).

TABLE III. Plausible candidate models (ΔAIC < 2) explaining *O. eremita* occurrence, separately for pitfall trapping (a) and wood mould sampling (b). Models are ranked according to their second-order Akaike's information criterion (AICc). Parameter estimates, number of parameters (k), proportional reduction in deviance (Red. Dev. %) and model weight (w_i) are reported. For continuous variables we reported the coefficient, while for categorical variables, "+" indicates that the variable was included in the model. Models were generalized linear mixed models with site as random factor.

Parameter estimates									k	Red. Dev.%	ΔAICc	w_i
Intercept	NEH	AEH	DIAM	DWM	H	M	PWMSo	SWM				
(a) Pitfall trapping												
-1.01		1.15							3	3.0	0.00	0.20
-1.11	+	1.41							5	6.8	0.32	0.17
-3.00			4.49						3	2.1	0.89	0.13
-1.42									2	0.0	0.98	0.12
-2.19		0.96	3.17						4	4.0	1.10	0.12
-1.93	+	1.12	2.21						6	7.6	1.70	0.09
-2.88	+		3.67						5	5.5	1.73	0.09
-1.62	+								4	3.2	1.88	0.08
(b) Wood mould sampling												
-2.31					+	+	+	+	13	28.4	0.00	0.32
-2.91					+	+		+	9	21.5	1.10	0.19

Variable names are presented in TABLE II.

Discussion

In our study, as well as in another study carried out in Italy (Carpaneto *et al.*, 2010), the frequency of occurrence was lower in comparison to Northern Europe (Table IV). One explanation for this may be that in our study area, the amount of wood mould was generally small. However, we observed a comparatively high frequency of occurrence of larvae (Table IV). This may be because most of surveyed cavities were small, and consequently all would mould is surveyed. In larger cavities larvae escape sampling more often because they usually occur deeper in the wood mould (Ranius & Nilsson, 1997). The lower frequencies of fragments of adult beetle body parts in Italy (Table IV) may be an effect of lower frequency of occurrence, but also that the fragments are decomposed quicker or that the population size per tree is low in comparison to Sweden.

Connectivity to dispersal sources was not a significant predictor in our study. In other studies, the frequency of presence of *O. eremita* has been higher it trees with a high frequency of suitable hollow trees within a radius of 200 m (Ranius, Johansson & Fahrig, 2011). In telemetric studies, observed dispersal ranges have been longer in Italy in comparison to Sweden (Chiari *et al.*, unpubl. data). Therefore, the effects of connectivity are expected to act at larger scale in Italy and the lack of connectivity effect might be due to the small size of our study sites.

The frequency of presence in wood mould samples was higher where the wood mould was dry or half-moist, and *O. eremita* was never found in cavities with wet wood mould. As in most studies in northern Europe (Table IV), a positive relationship between the amount of wood mould and the frequency of occurrence of *O. eremita* was observed. In our study, *O. eremita* was more frequent in trees with more than 4 l of wood mould. Kelner-Pillault's (1974) measurements of willow tree cavities show that temperature is more stable deeper in the wood mould compared with the surface, and the wood mould buffers the moisture in the cavity by absorbing water (Ranius & Nilsson, 1997). Therefore, larvae experience more stable microclimatic conditions if there are larger volumes of wood mould.

Habitat characteristics related to warmer conditions (habitat openness and sunny directions) affect the occurrence of *O. eremita* in Sweden, but not in Italy (Table IV). It has been found that feeding activities take place when the daily mean temperature exceeds 13ºC

(Pawłovski, 1961). Our result suggests that in northern Europe, where the macroclimate is cooler, microclimate is to a higher extent a limiting factor for larval development.

In this, and also in a previous study (Ranius *et al.*, 2009), *O. eremita* has been less frequent in hollows with entrances close to the ground. Furthermore, the species is less frequent in hollows in which there is a high proportion of soil in the loose material. Since the beetle is eating rotten wood, a large proportion of soil indicates that there is less food, which may be due to that much of the wood mould has already been consumed by *O. eremita* or other decaying organisms.

Conclusions

The suitability of a hollow tree for *O. eremita* is determined by several ecological predictors. The amount of wood mould is the primary factor that affects the frequency of occurrence of *O. eremita* across its distributional range. Also the microclimate is important, since in our study the species avoid wet hollows, while in northern Europe factors indicating a warm microclimate are positively related with species' occurrence.

The results of our study provide important information for the management of the habitat of this endangered species. The comparison between southern and northern regions indicated that differences in macro-climatic conditions modify the species' habitat requirements and therefore conservation measures should be tailored to different local conditions. In northern Europe, it is desirable to maintain or increase the habitat openness to obtain a warm microclimate. On the contrary, in southern regions, it seems that no gain is achieved by increasing the habitat openness. Both in northern and southern Europe, trees with large amounts of wood mould should be preserved irrespective of tree species.

TABLE IV. Comparison of 8 studies on the habitat of *Osmoderma eremita* (+ = significant positive relationship; - = significant negative relationship). These are all studies we are aware of, in which presence/absence of *O. eremita* has been assessed with a standardised method.

TABLE IV continued

	NORTHERN EUROPE (Sweden)					CENTRAL EUROPE (France)	SOUTHERN EUROPE (Italy)	
	Ranius & Nilsson, 1997	Ranius & Jansson, 2000	Jönsson, 2003	Ranius *et al.*, 2009	Ranius *et al.*, 2010	Dubois *et al.*, 2009	Campanaro *et al.*, 2010	Present study
Methods	woodmould sampling pitfall trapping	wood mould sampling pitfall trapping	wood mould sampling pitfall trapping	pitfall trapping air sampling	wood mould sampling	wood mould sampling	wood mould sampling pitfall trapping visual checking olfactory searching	pitfall trapping wood mould sampling
Study sites	southeastern Sweden	southeastern Sweden	southernmost Sweden	southeastern Sweden	southeastern Sweden	western France	central Italy	central Italy
No. of surveyed trees	135	90	23	59	281	199	66	206
Tree species with species occurrence	*Quercus robur* *Fraxinus excelsior*	*Quercus robur*	*Quercus robur* *Fagus sylvatica*	*Quercus robur*	*Quercus robur*	*Fraxinus excelsior* *Quercus robur* *Malus domestica* *Alnus glutinosa* *Populus sp.* *Salix sp.* *Castanea sativa* *Pyrus communis*	*Quercus ilex*	*Ostrya carpinifolia* *Quercus suber* *Acer obtusatum* *Quercus pubescens*
Habitat	pasture woodland	pasture woodland	pasture woodland beech forest	pasture woodland	pasture woodland	orchards hedgerows	city park	pasture woodland
Frequency of occurrence with pitfall trapping (%)	67*	31	100*	58				12
Frequency of occurrence with wood mould sampling (%)						12		
Larvae	8						3	15
Frass	86				+	+		
Fragments	48		+	+	+	+	17	9
Adults					+			1
Predictors								
Annual growth rate of trees				-				
Connectivity					+	+		
Density of surrounding foliage	+						+	+
Distance between entrance and woodmould surface	+	+	+	+	+	+		
Habitat openness					+		+	+
Height								+
Moisture								+
Number of entrance hole							-	
Presence of dry matter	+							+
Proportion wood mould in relation with soil								+
Sampled volume of wood mould				+				+
Size of entrance hole							+	
Status of the root collar							-	
Sunny direction	+		-					
Tree diameter	+	+	+	+				+
Tree species								
Volume of wood mould	+			+	+	*Quercus robur* *Malus domestica*		

TABLE IV continued
* trapping was only employed in trees with remains from adult beetle body parts.

APPENDIX A. Pearson correlation coefficients of measured tree characteristics. Coefficients exceeding 0.65 in bold.

	CON	NEH	CLO	FDS	FDC	DS	S	DIAM	H	AEH	DWM	TWR	AWM	SWM	M	PWMSo
CON																
NEH	0.19															
CLO	0.24	-0.08														
FDS	0.17	-0.03	0.61													
FDC	0.12	0.04	0.51	**0.87**												
DS	-0.22	-0.21	-0.08	-0.19	-0.13											
S	0.44	0.17	0.09	0.11	0.08	-0.07										
DIAM	0.45	0.06	0.21	0.15	0.13	0.01	0.21									
H	0.18	0.03	0.04	0.20	0.22	-0.17	0.15	-0.08								
AEH	0.16	0.16	0.00	0.00	0.00	-0.08	0.36	0.34	-0.28							
DWM	0.20	0.23	-0.02	0.13	0.14	-0.21	0.15	-0.01	0.36	0.06						
TWR	-0.14	0.09	-0.01	-0.06	-0.02	0.11	-0.11	-0.02	-0.20	0.06	-0.04					
AWM	0.37	0.27	0.02	0.03	0.06	-0.18	0.29	0.49	-0.13	0.59	0.13	0.13				
SWM	0.26	0.18	0.00	-0.05	-0.09	-0.08	0.25	0.35	-0.02	0.46	0.18	0.19	**0.66**			
M	0.46	-0.13	0.29	0.34	0.30	-0.18	0.27	0.14	0.32	0.01	0.15	-0.20	0.12	0.15		
PWMSo	-0.14	-0.04	0.03	0.01	0.01	0.09	-0.09	-0.11	-0.40	0.05	-0.22	0.11	-0.08	-0.21	-0.21	

Variable names are presented in TABLE II.

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CHAPTER 3

PAPER III

CHAPTER 4

Dispersal patterns of an endangered saproxylic beetle, *Osmoderma eremita*, in Mediterranean woodlands

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Abstract. 1. Dispersal patterns of a beetle inhabiting tree hollows, *Osmoderma eremita* (Scopoli, 1763) (Coleoptera: Cetoniidae), were studied in a cork oak (*Quercus suber*) woodland in central Italy, the southernmost part of its distribution range. During two years, we used radio telemetry to monitor dispersal of 39 free-ranging individuals (16 males, 23 females).
2. Telemetered beetles spent their life time not only inside hollow trees but also in other habitats, such as on the ground surface and under the ground level.
3. Beetles were more active at the beginning of the season. 81% of the males and 69% of the females conducted dispersals during their life-time.
4. The dispersal distance over individuals' life-time did not differ between sexes. The longest dispersal was conducted by a female that moved 1504 m and 39% of dispersing individuals reached distances farther than 250 m.
5. The distribution of *O. eremita* dispersal distances over individuals' life-time best fit with the power function, which predicts that 9.7% of beetles move distances farther than 1600 m.
6. Both dispersal rate and range are higher than what has been found in northern Europe. However, since the population size per tree is low, and a high predation rate (at least 28%) was observed in dispersing beetles, it is probably desirable to concentrate the density of hollow tree also in southern Europe.

Keywords: Dispersal, habitat colonization, Coleoptera, Scarabaeidae, radio tracking, hollow trees.

Introduction

Dispersal is a fundamental process in ecology, affecting population dynamics and species distribution (Bowler & Benton, 2005; Clobert *et al.*, 2004). Nature conservation benefits from a high level of understanding of dispersal to improve its strategies, especially regarding the spatial distribution of conservation efforts (Macdonald & Johnson, 2001; Trakhtenbrot *et al.*, 2005).

Insects may be used as model species in dispersal studies, because they are species rich, and may occur in large populations that are easy to study (Clobert *et al.*, 2001). Several methods are available to study insect dispersal, e.g. mark-recapture (Arellano *et al.*, 2008; Cronin *et al.*, 2000), harmonic radar (O'Neal *et al.*, 2005; Riley *et al.*, 1996), tethering experiments (Boiteau & Colpitts, 2001; Dubois *et al.*, 2010) and radio telemetry (Beaudoin-Ollivier *et al.*, 2003; Hedin & Ranius, 2002; Rink & Sinsch, 2007). These methods give different types of information, with different risks of biases. Radio telemetry has been a valuable tool in the study of animal movements since about 60 years ago (Kenward, 2001; Mech, 1983). Since the early 1990's, miniature transmitters facilitate telemetric studies on smaller animals (Riecken & Raths, 1996). Radio telemetry allows researchers to follow the movements of many individuals at the same time and in natural conditions, usually with limited disturbance of their activities.

A large proportion of forest insects are saproxylic, i.e. dependent on dead wood or on other saproxylic organisms (Speight, 1989). In Europe, many saproxylic insects are today threatened (Nieto & Alexander, 2010), owing to intensive commercial forestry and changed agricultural management practices, which have decreased the amount and quality of dead wood (Davies *et al.*, 2008).

Osmoderma eremita (Scopoli, 1763) (Coleoptera: Scarabaeidae, Cetoniinae) is a 3 cm-large flying beetle inhabiting hollow trees, and is one of the few saproxylic insects protected in the EU countries by the Bern Convention (Appendix 2) and the Habitat Directive (Annex II, IV). It is also included in the IUCN Red List of threatened species as Near Threatened (Nieto *et al.*, 2009). *O. eremita* could be used as an indicator of high conservation value, as the species richness of other specialized beetles in tree hollows is considerably higher where the species is present (Ranius, 2002). This may be because *O. eremita* affects the rotten wood habitat both physically and chemically, in a favorable way for other species (Jönsson *et al.*,

2004). In Sweden, O. *eremita* has exhibited a limited dispersal rate and dispersals of up to 300 m have been observed (Svensson *et al.*, 2011). However, in France, Dubois & Vignon (2008) reported for one individual a total dispersal of 700 m. In a tethered flight experiment, the movements ranged from 20 to 1500 m, with a maximum cumulative flight distance of one individual of 2400 m (Dubois *et al.*, 2010).

A species' ecology may vary within its distribution range, in response to different climatic conditions, or habitat and landscape characteristics (Dover & Settele, 2009). As dispersal parameters may be very specific for populations inhabiting certain landscapes (Mennechez *et al.*, 2004), dispersal should be studied in several different ecological and geographical contexts. Regarding *O. eremita*, no dispersal study has so far been conducted in the southern part of its range, i.e. in southern Europe.

This is a radio tracking study of *O. eremita* carried out in Italy. Our aim is to address the following questions: (1) How much time do the adults spend in tree hollows and in other habitats? (2) Have the adults a specific daily or seasonal activity pattern? (3) Have the adults a preferred time period for flying during the season? (4) Are there differences in dispersal rate and dispersal range between sexes? (5) Are there any differences in dispersal rate and range between populations of southern, central and northern Europe?

Materials and methods

Study area

The study area is a cork oak (*Quercus suber*) woodland (120 ha), situated near the village of San Vito, in southern Latium (central Italy, UTM 33 N, WGS 84, 362804 4584512, between 26 and 150 m above sea level) (Fig. 1). This is one of the largest cork oak woodlands of Italy. The tree cover is dominated by cork oaks but includes also other species of both deciduous and evergreen trees (Testi & Lucattini, 1994). This woodland was devoted to cork production for long time but now such activity has almost been abandoned. We searched systematically for trees suitable for *O. eremita* through the study area and found 120 hollow trees (114 *Quercus suber*, 3 *Q. ilex*, 2 *Q. pubescens*, 1 *Q. frainetto*), 40 old trees (*Q. suber*) without cavities but with big fractures in the trunk, 2 dead

standing trees and 7 stumps of *Q. suber*. All trees were mapped using a Garmin GPS (MAP 60 CSX).

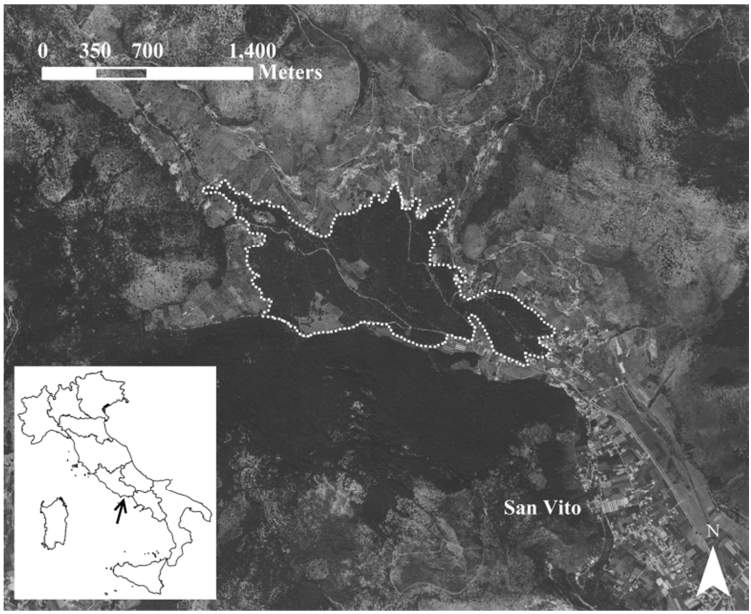


Fig. 1. Overview of the study area for the radio telemetry study of *Osmoderma eremita*. The dotted line shows the size and configuration of the cork oak stand included in the SCI "Sugherete di San Vito e Valle Marina" (IT6040005).

Data collection

To collect beetles, we used 68 pitfall traps and 14 black cross window traps, set in 68 hollow trees (66 *Q. suber*, 1 *Q. ilex*, 1 *Q. pubescens*) during two years (2009-2010), from 20th June until 31st July. In Italy, adults of *O. eremita* have been found from June to August (own observation). All traps were emptied every day, and beetles were also visually searched for one hour per day. Pitfall traps were plastic jars, placed with the opening on the level with the wood mould surface, like in Ranius & Hedin (2001). Black cross window traps were the same as those used by Svensson & Larsson (2008), and were baited with a pheromone, a neat racemic mixture of γ-

decalactone (Sigma-Aldrich, USA). Dispensers for traps were 2 ml plastic eppendorf vials where we inserted cut strings of cotton as wicks. Dispensers were loaded with 1200 µl of the racemic mixture and then removed after the first two days to avoid any influence on the telemetric study. We captured 39 individuals (19 by black cross window traps, 14 by pitfall traps and 6 by visual searching), and tagged them by radio transmitters (Table 1). At first capture, we measured the total body length and body mass of each individual. The total body length was measured with a calliper rule (precision 0.05 mm). The body mass was weighted with a portable balance (PESOLA AG, Switzerland) (precision 10 mg). Each beetle was given an individual number by marking each elytron with a small drill. No beetle was damaged by the marking procedure. Each beetle was equipped with a radio transmitter (LB-2N, 0.45 g, Holohil Systems Ltd., Canada). The transmitters had a nominal life time of 21 days but, in our study, they lasted 13 to 22 days (mean: 17). In nature, the maximum life-time of *O. eremita* adults is about one month (Ranius *et al.*, 2005). The antenna was reduced to 5 cm and adjusted above the elytral suture to limit the disturbance of beetle behaviour. Transmitters were attached to the pronotum using a cyanoacrylate glue (LOCTITE, Super Attack flex Gel, Henkel). According to Boiteau & Colpitts (2001) electronic tags should weigh no more than 33% of the beetle's weight to avoid impact on the flights; in our study the transmitter weight was up to 32% of the initial body weight (Table 1). To detect the transmitter signals, we used a handheld antenna (Yagi three elements, Wildlife Materials Inc.) connected to a radio receiver (NEW TRX-1000S W, Wildlife Materials Inc.).

The radio-tagged beetles were released into the hollow tree where they had been captured. After that, the location of each beetle was determined by 'the homing technique' (White & Garrott, 1990). Coordinates of each location were identified using a GPS. The homing procedure always started at the last known location of the individual and lasted between a few minutes and some hours. In order to avoid direct interference with the tagged beetles, we did not approach closer than 0.5 m. In most cases, visual detection was possible, but not when individuals were underground or deep in a cavity. If a beetle remained at the same place from one day to another, we waited at least two days before checking for a possible loss of transmitter or death of the beetle. When we did not find a

beetle we searched for it by walking from the starting point to a distance of 800 m in all directions. Beyond this radius, we continued to search the beetles mainly following the roads by car, up to 2 km from the starting point.

To obtain information on beetle activities during day and night, we performed four shifts every four-day period: 1st day) from 0:00 to 6:00; 2nd day) from 6:00 to 12:00; 3rd day) from 12:00 to 18:00; 4th day) from 18:00 to 24:00 and so on, until the end of the study period. During each shift, for each beetle, we made usually one homing per hour. We noted whether the beetle was on or inside a tree or anywhere else, the vertical position (i.e. underground, on ground surface, or above the ground surface), and whether it was active or not. A beetle was considered to be active if: 1) the signal amplitude from the transmitter was fluctuating (indicating that the animal was moving), or 2) it was visually observed to be walking or flying, or 3) the beetle changed position during the last hour.

Table 1

Morphological features of 39 radio-tagged *Osmoderma eremita* (mean ± standard deviation) and percent ratio between transmitter and body weight.

Year	Sex	N	Total body length (mm)	Body mass (g)	Transmitter load (%)
2009	M	1	29.9 ± 0.0	1.4 ± 0.0	29.6 ± 0.0
	F	8	31.4 ± 1.1	2.0 ± 0.3	20.3 ± 2.8
2010	M	15	30.0 ± 2.1	1.7 ± 0.6	25.4 ± 7.1
	F	15	28.7 ± 1.6	1.6 ± 0.4	25.6 ± 5.0
Total	M	16	30.0 ± 2.0	1.7 ± 0.6	25.7 ± 6.9
	F	23	29.7 ± 1.9	1.8 ± 0.4	23.8 ± 5.0

Data analysis

To compare activity and dispersal of the beetles during adult lifetime, we divided the study season in three periods: 1) from 23rd June to 5th July, 2) from 6th to 18th July, and 3) from 19th to 31st July. We made analyses of all dispersal movements (> 5 m) and separate analyses of movements exceeding 25 m. This was because we assumed movements exceeding 25 m were flying events, while shorter movements may have taken place either by flight or walking. We tested differences between sexes by the Unpaired Student's t-test, the Mann-Whitney U-test and the Yates corrected χ^2 test. The Mann-Whitney U-test was used also to test differences between transmitter weight and body mass in flying and non-flying beetles. The activity rate was calculated by dividing the number of observations revealing activity by the total number of observations for each individual. A χ^2 test was used to compare the proportion of active and dispersing individuals, and Fisher's exact test for the proportion of flying individuals, between the three study periods. To test the data distributions we used the Shapiro test.

As in Hedin *et al.* (2008), we calculated an adjusted dispersal rate, which takes into account that beetles may disperse before the tagging or after the transmitter ceased to function. Then we assumed that the daily dispersal rate is constant over the beetles' lifetime. The adjusted dispersal rate, D_{life}, was estimated as:

$$D_{life} = 1 - [(1 - D_{day})^m]$$

where D_{day} = proportion of days with observed dispersals among tagged beetles, and m = mean life-time of adults. The mean life-time of adults was provided from the survival rate estimated by the Cormack–Jolly–Seber model, with survival rate and recapture probabilities assumed to be constant, using the program MARK (White & Burnham, 1999). Radio tracking days were treated as control days in a capture-mark-recapture study, and presence/absence of living telemetered beetles was treated as capture histories. Life-time was estimated separately for males and females.

The dispersal distance distribution of our data was compared with a negative exponential function, $P = \exp(-D/k)$, and a power function, $P = aD^{-n}$, where P is the probability that an individual cover the distance D or farther, and a, n, and k are constants.

Analyses were performed with STATISTICA 7.0 (StatSoft Inc.), using a significance level of 0.05 to reject the null hypothesis.

Results

Tracking periods

The tracking period of individuals varied between 2 and 33 days (mean 9 days), with no difference between sexes (t_{37} = 0.005, P = 0.996). About 15% of the individuals (6/39) were lost because the battery life finished before their death. For the remaining 85%, the tracking period was shorter than the nominal battery life time, either because the beetles died before the end of the battery (21/39), or because radio signals ceased (12/39) for unknown reasons (e.g. for technical reasons or because the beetles flew outside the detection range).

Association with hollow trees and vertical positions

Beetles spent about 80% of the tracking period on or inside hollow trees and 20% in other habitats (Fig. 2). There was no difference between males and females in the association with hollow trees (U = 139.5, P = 0.177). Regarding vertical position, both sexes were mostly found above the ground level, but there was a significant difference between males and females (U = 99.0, P = 0.015) (Fig. 2); males occurred more frequently on ground in comparison to females.

Activity patterns

The beetles were active at any hour of the day (Fig. 3). They were significantly more active during the first study period (23rd June–5th July) in comparison to the two subsequent periods (6th–18th and 19th–31st July) (χ^2_2 = 14.834, P < 0.01).

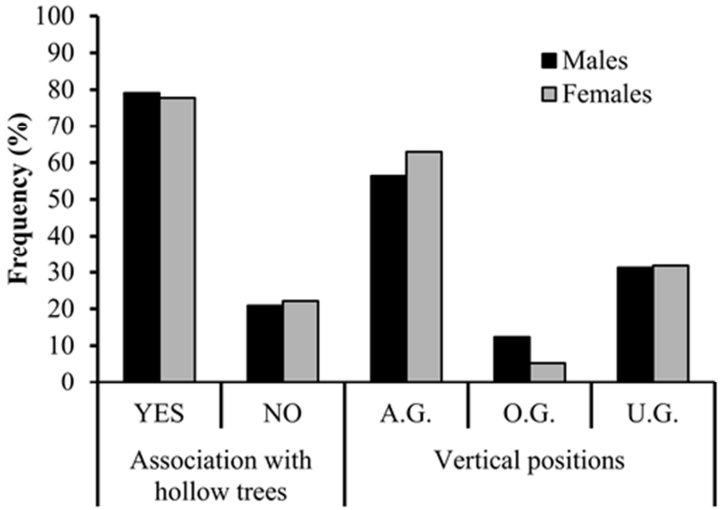


Fig. 2. Position of observed beetles. Whether they were found in hollow trees or not (YES = inside or on hollow trees; NO = other habitats) and their vertical positions (A.G. = above ground surface; O.G. = on ground surface; U.G. = underground).

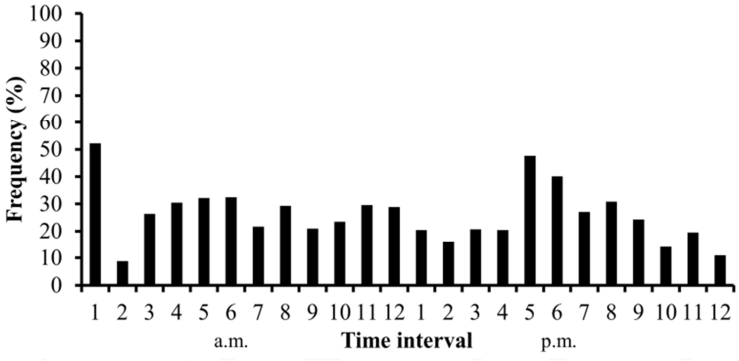


Fig. 3. Daily activity pattern of *Osmoderma eremita*. Proportion of telemetered beetles observed to be active in relation to the day hours.

Flight patterns

Movements exceeding 25 m (flights) were recorded in 25% of the males (4/16) and 30% of the females (7/23). For both sexes, the median ratio between transmitter weight and body mass in flying beetles did not differ significantly from non-flying beetles (males: U = 12.0, P = 0.170; females: U = 54.5, P = 0.922).

Flights took place from 27th of June to 17th of July (Fig. 4) with significantly more frequent flights during the first two study periods (23rd June–18th July) in comparison to the third one (19th–31st July) (Fisher's exact test: no. of tables evaluated = 105, P = 0.039).

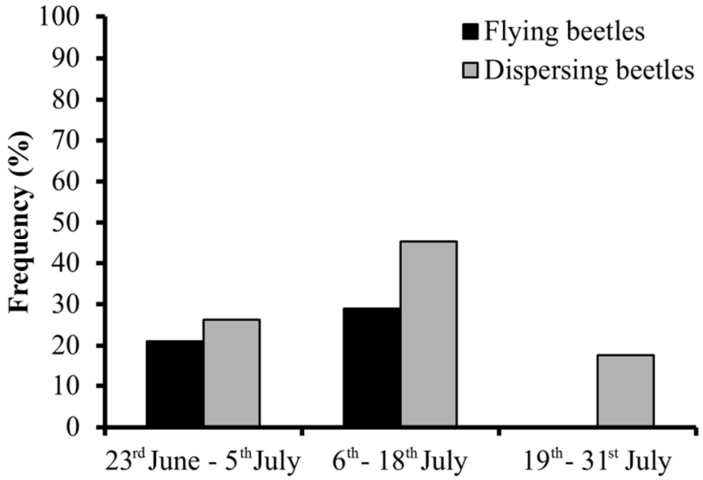


Fig. 4. Beetle dispersal activities during the three study periods. Proportion of beetles with movements exceeding 25 m (flying beetles) and of beetles with movements exceeding 5 m (dispersing beetles).

Dispersal patterns

A total dispersal range exceeding 5 m was recorded in 56% of the males (9/16) and in 39% of the females (9/23) (Table 2). The difference between sexes was not statistically signinficant (χ^2_1 = 0.530, P > 0.05). The dispersal rate over individuals' life-time ('adjusted dispersal rate') was estimated to be 81% for males and 69% for females (Table 2). Dispersal took place during the whole season (Fig. 4) with no difference between the three study periods (χ^2_2 = 4.280, P > 0.05).

The median daily dispersal distance (excluding zero values) differed between sexes (U = 11.0, P = 0.028): it was 58 m (range: 9–357 m) for females and 14 m (range: 5–41 m) for males. Throughout the season, the longest dispersal distance was reached by a female that moved 1504 m, while the longest dispersal distance for a male was 299 m (Fig. 5). The dispersal distance over individuals' life-time did not differ significantly between sexes (median: females, 249 m; males, 28 m; U = 22.0, P = 0.113).

The distribution of dispersal distances observed (total over the whole life-time) fit better with the power function (Pearson Correlation Coefficient: r_p = 0.966) (Fig. 6) than with the negative exponential function (r_p = 0.845). In the negative exponential function, P = exp (-D/k), the value of *k* (= mean dispersal distance) was estimated to 308 m.

Table 2

Dispersal activities and mean life time of telemetered *Osmoderma eremita* beetles in the two years of sampling (2009-2010). The dispersal rate is the proportion of individuals for which at least one dispersal was observed, while adjusted dispersal rate is an estimate of the dispersal rate over life-time.

	Sex	2009	2010	Total
Dispersal rate (%)	M	0	60	56
	F	63	27	39
Mean life-time (days)	M	-	12	13
	F	17	11	12
Daily dispersal rate (%)	M	0	13	12
	F	13	6	9
Adjusted dispersal rate (%)	M	-	82	81
	F	91	48	69

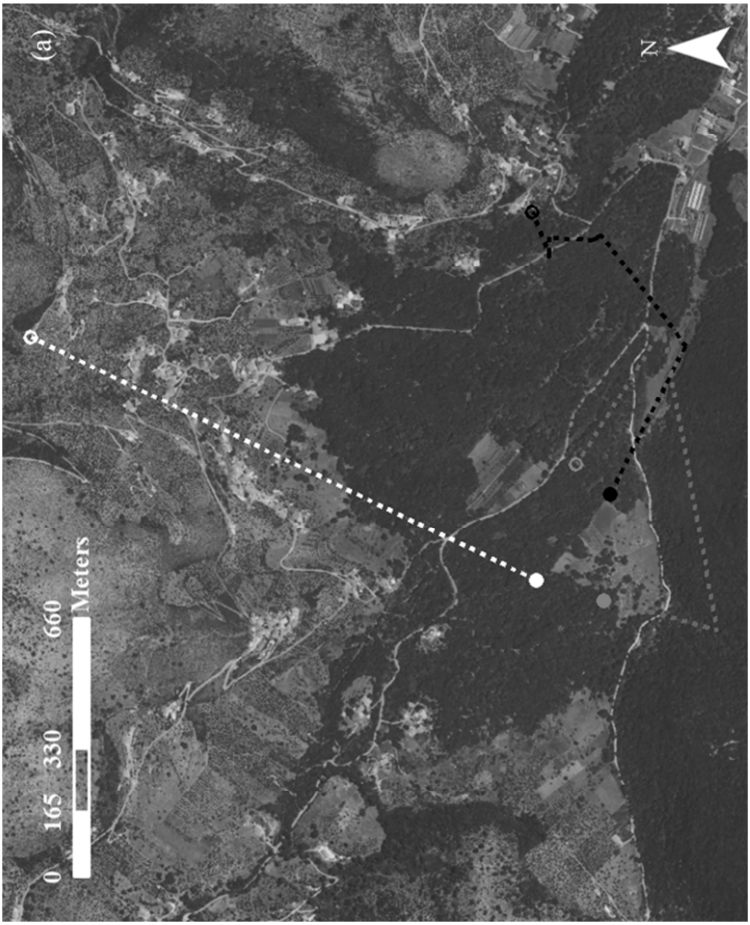
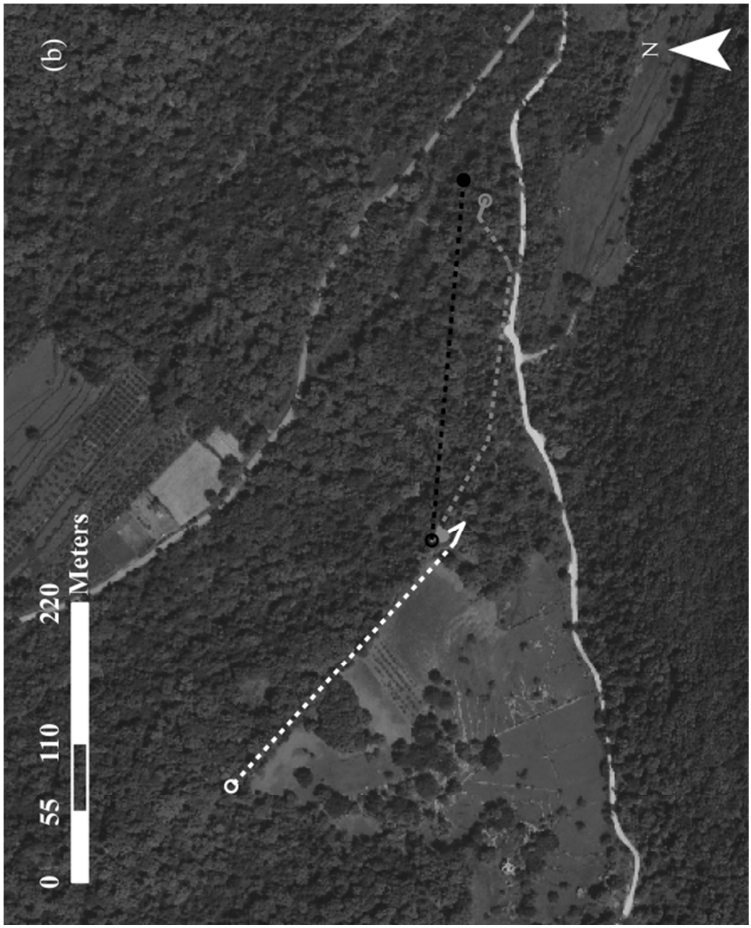


Fig. 5. The movement patterns of three females and three males of *Osmoderma eremita* with the longest total dispersal range. (A) Females: grey line, 1504 m; white line, 1442 m; black line, 1102 m. (B) Males: grey line, 299 m; white line, 297 m; black line, 285 m. Each track starts with filled circle and ends with open circle; dotted and continuous lines represent movements longer and shorter than 25 m, respectively.



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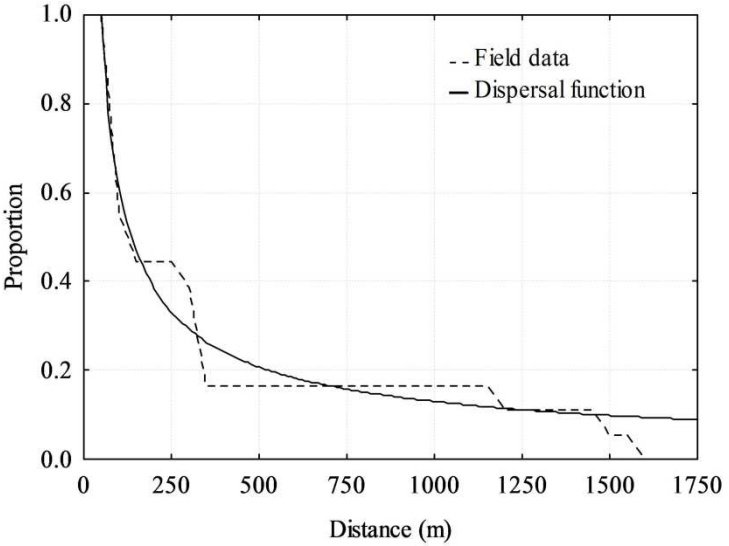

Fig. 6. Proportion of dispersing *Osmoderma eremita* individuals with dispersal ranges (over the whole life-time) exceeding certain distances. Field data from telemetry (n = 18) are compared with a power function $P = aD^{-n}$, where P is the probability that a dispersing individual exceeds the distance D (m).

Discussion

Association with hollow trees and vertical positions

Our results confirm that the adults of *O. eremita* spend most of their life time in association with hollow trees, mainly in the cavities but also on the bark and inside tree roots. However, we observed that beetles occurred also in other habitats: in the litter, near the base of young or old cork oak trees, under shrubs (*Erica arborea, Rubus* spp.) or ferns (*Pteridium aquilinum*), and under the moss cover of rocks. Most often, the adults were found in cavities situated up to 5 m from the ground. When the beetles were under the ground level, they were always close to plant roots or inside roots of old trees. Beetles were found also on the ground surface, males more frequently than females, but only for short periods. This is the first time that *O. eremita* has been found to occur on and under the ground (cf. Ranius

et al., 2005, who document observations done all over Europe). In Sweden, a telemetric study has revealed that adults of *O. eremita* occur only in trunk hollows with wood mould (Hedin *et al.*, 2008). Our results show that in Italy, *O. eremita* may occur in a wide spectrum of microhabitats in comparison to northern populations. Probably, these places are transient shelters used by dispersing individuals.

Activity patterns

In our study, beetles were equally active night and day. In Sweden, *O. eremita* has been found to be active only at day-time, while in Russia active adults have also been observed at dusk and night (Ranius *et al.*, 2005). Also in Germany and France active adults have been observed at dawn (Schaffrath, 2003; Stegner, 2002). Slobodchikoff (1983) showed that tenebrionid beetles become active when the combination of temperature and humidity is optimal for metabolism. Thus, differences in the daily activity pattern of *O. eremita* may be due to differences in day and night conditions over the species' distribution range.

Beetles of both sexes flew only during the first two thirds of the study period. During the last part of the study period, beetles only moved distances shorter than 25 m. A similar pattern was reported by Dubois & Vignon (2008), who observed an individual performing long flights followed by short walks. Fadamiro & Wyatt (1995) showed that the flight behavior of a beetle, *Prostephanus truncatus*, is affected by their age and the quality of food or oviposition sites, with a peak in dispersal rate before reproduction, when beetles disperse from habitat of low quality to optimal reproductive sites. For *O. eremita*, it seems that they usually disperse after mating (Svensson &. 2011).We do not know when females lay eggs, but the present study suggests that they disperse relatively early, probably often before laying eggs. Given that the adults rarely eat (Ranius *et al.*, 2005), it may be that their capacity to fly is weakened during the end of their life-time, since their energy resources end.

In July, we observed a female eating on a rotten apricot on a tree (*Prunus armeniaca*), after crossing an area of open, unsuitable habitat over a distance of 1000 m (Fig. 5A). *O. eremita* has rarely been observed feeding on flowers (*Leucanthemum* sp., *Viburnum* sp., *Sambucus nigra*), on sap flows and on ripe yellow plum (*Prunus*

domestica), and in the laboratory it can be fed with bananas and apples (Ranius *et al.*, 2005). Feeding may be linked to longer dispersal either to search for food resources, or due to an increased energy supply. On the other hand, feeding may increase the predation risk in comparison to if the beetles remain in tree hollows. The present study confirms that adults of *O. eremita* rarely feed. Nevertheless, plum and apricot trees could be planted at sites with *O. eremita* to provide food, even though the maintenance of hollow trees is most likely much more important.

Dispersal patterns and behaviour

The dispersal rate of *O. eremita* observed in the present study was higher than in previous studies (Table 3). This may be explained by a higher summer temperature in Italy, which can enhance dispersal. A study in Sweden indicates that the dispersal rate is temperature dependent, and higher in warm summers in comparison to cooler summers (Larsson & Svensson, 2009).

Only in 7% of the dispersals (3/44), the beetles moved from one cavity to another. Most of the dispersals ended up underground, in the litter, or near the base of bushes, ferns or trees. This implies that *O. eremita* uses shelter places as stepping stones during the dispersal. At least 28 % of dispersing beetles (5/18) were predated. We found their remnants in two cases under nests of crows (*Corvus corone cornix* or *Garrulus glandarius*), in two cases in owl pellets, and in one cases the predator was unknown. On the contrary, no predation of dispersing beetles was observed in telemetric studies in Sweden (Hedin *et al.*, 2008) and France (Dubois & Vignon, 2008). The higher mortality observed in Italy may be due to that the beetles spend more time dispersing there.

There was no difference in the dispersal rate between males and females. The daily dispersal distance was longer for females than for males, but the overall dispersal distance did not differ statistically between sexes. In a thethered flight experiment (Dubois *et al.*, 2010), females moved further and faster than males (Table 3). In *O. eremita*, males are releasing pheromones that attract females (Larsson *et al.*, 2003). In two other lamellicorn beetles, the dispersal distance is also sex-biased: in *Scapanes australis*, whose females follow the trails of pheromone released by males, dispersal distances are female-biased (Beaudoin-Ollivier *et al.*, 2003), whereas in *Lucanus cervus*, whose

Table 3

Comparison of six studies on the dispersal of *Osmoderma eremita* (Methods: CMR = capture-mark-recapture; RAD = radiotelemetry; TET = tethered flight; * = telemetered beetles; F = beetles captured with funnel traps; P = beetles captured with pitfall traps).

		NORTHERN EUROPE (Sweden)			CENTRAL EUROPE (France)			SOUTHERN EUROPE (Italy)
		Ranius and Hedin, 2001	Hedin et al., 2008	Svensson et al., 2011	Dubois and Vignon, 2008	Dubois et al., 2010		Present study
		(CMR)	(RAD)	(CMR+RAD)	(RAD)	(TET)		(RAD)
No. of beetles		839	65	>1000	17	30		39
	Male	-	39	-	10	-		16
	Female	-	26	(*41)	7	-		23
No. of dispersing beetles		8	8	122	1	14		18
	Male	7	5	25	0	8		9
	Female	1	3	97 (*24)	1	6		9
Dispersal rate (%)		15	12	-	6	47		46
	Male	-	13	-	0	-		56
	Female	-	12	(*58)	14	-		39
Dispersal range (m)		30-190	10-180	not reported-306	680	21-2361		5-1504
	Male	30-190	-	-	-	-		5-299
	Female	70	-	-	680	-		46-1504
Mean dispersal distance ± standard deviation (m)		85 ± 57	-	F 66 ± 17 (*71 ± 17) P 107 ± 161	-	-		344 ± 487
	Male	87 ± 61	-	F 40 ± 14 P 124 ± 124	0	713 ± 128		112 ± 137
	Female	70 ± 0	-	F 73 ± 17 P 97 ± 173	364 ± 304	1086 ± 135		575 ± 603
Significant difference between sexes		no	no	no	yes	yes		no

males search for the female scent, distances are male-biased (Rink & Sinsch, 2007). Thus, for these three species, the sex that follows pheromones disperse over longer distances than the sex releasing the pheromones.

The maximum dispersal distance observed during this study (1504 m) exceeded those observed in previous field studies (Table 3). Our results corroborate those from tethered flight experiments (Dubois *et al.*, 2010) (Table 3) as they show that dispersal of more than one kilometre is possible also in nature. Even though such long dispersals are rare events, they may be important for metapopulation viability as they allow colonization of new habitat patches (Nathan *et al.*, 2003).

The power function curve predicts that 61.7% of the dispersing beetles move distances ≥ 100 m, 33.2% more than 250 m and 9.7% more than 1600 m. In Ranius (2006) data on *O. eremita* fitted best with the negative exponential function, which predicted that 1.6% of dispersing beetles move ≥ 250 m. Thus, our estimates are considerably higher than that calculated from Swedish data. In Sweden, the species is obviously sensitive to habitat fragmentation, since the probability of occurrence is higher in hollow trees with a high density of potential dispersal sources in the close vicinity in comparison to more isolated trees (Ranius *et al.*, 2010). Such studies have not been done in southern Europe, but we believe that the species is sensitive to habitat fragmentation also there. This is because we observed a low population density and a high dispersal mortality by predation in our study.

Methodological issues

Available miniature transmitters seem to be small and lightweight enough to not disturb dispersal activities of *O. eremita*. This is supported by the absence of difference in the ratio between transmitter weight and body mass in flying and non-flying beetles. We observed no losses of the radio antenna or of the complete transmitter. We lost contact with a lower proportion of tagged beetles in comparison to Hedin & Ranius (2002), maybe because we put a glue coating on the soldered leads in order to avoid problems with humidity, instead of wax. Contact was usually established at a distance of 50–100 m. The longest recorded detection range was about 1300 m, of which 1100 m crossed agricultural fields (Fig. 5A).

In most cases we identified the tree where the beetle was located, but sometimes we lost the contact when the beetles moved deep in the soil or in hollow trees.

Conclusions

In Italy, *O. eremita* is able to move up to 1.5 km, which is much longer than has been observed in central and northern Europe. This dispersal range is similar to those observed in other large saproxylic beetles as *Rosalia alpina*, up to 1.6 km (Drag *et al.*, 2011), and *Lucanus cervus*, up to 2.0 km (Rink & Sinch, 2007). However, most of the individuals remains within a few hundreds of meters of their natal tree.

The Swedish populations of *O. eremita* have been described as metapopulations, with each hollow tree potentially harbouring a local population, only weakly connected by each other by some dispersal between trees (Ranius, 2007). The Italian populations in this study have a rather different structure, since the hollow trees only host a few *O. eremita* individuals, and the majority of adults leave their natal tree. Even though we conducted our study at a site which probably is one of the best for *O. eremita* in southern Italy, the population density was low, and the dispersal mortality high. Therefore, also in Italy *O. eremita* is sensitive to habitat fragmentation.

To allow long-term persistence of the species it is necessary to maintain existing old trees and allow the growth of new hollow trees in order to avoid gaps in space and in time.

Acknowledgements

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CHAPTER 5

Conclusions and implications for conservation

5.1 Conclusions

This is the first study concerning the ecology of *O. eremita* in a Mediterranean environment. Differently from northern Europe, where the demographic structure of this species has been explained by the metapopulation approach (Ranius 2000, 2007), in the southernmost localities (i.e. in Italy) a single hollow tree may host only a reduced number of individuals, which do not represent a population in itself, and a single population is widespread on the landscape. Also including a large number of hollow trees the population size appear to be small, as only a small fraction of trees harbour the species and most of them contained only a small amount of wood mould (<4 l).

The suitability of a hollow tree for *O. eremita* is determined by several ecological predictors, and the amount of wood mould is the primary factor that affects the frequency of occurrence of the species across all its distribution range. Differently from Sweden, where only the young hollow trees have a small amount of wood mould, in Italy even the oldest ones have a limited carrying capacity, thus the habitat quality is generally poor. Also the microclimate is important, since in our study the species avoided wet hollows, while in northern Europe factors indicating a warm microclimate are positively related with species' occurrence. In our study areas, where a lot of trees have basal cavities, the frequency of presence was higher in cavities with low soil contamination.

In Italy, *O. eremita* is able to move up to 1.5 km, which is much longer than has been observed in central and northern Europe. This dispersal range is similar to those observed in other large saproxylic beetles as *Rosalia alpina*, up to 1.6 km (Drag et al. 2011), and *Lucanus cervus*, up to 2.0 km (Rink and Sinch 2007). 81% of the males and 69% of the females conducted dispersals during their life-time. During dispersals beetles occurred in a wide spectrum of habitats in comparison to northern populations, i.e. in the litter, near the base of young or old cork oak trees, under shrubs (*Erica arborea*, *Rubus* spp.) or ferns (*Pteridium aquilinum*), and under the moss cover of rocks. All these places are probably transient shelters, like

stepping stones between suitable habitat patch (i.e. hollow trees). However, most of individuals remains within a few hundreds of meters of their natal tree, and a high predation rate (at least 28%) was observed in dispersing beetles. Both dispersal rate and range are higher than what has been found in northern Europe, but since population density is low and the mortality during dispersal is high, *O. eremita* is sensitive to habitat fragmentation also in Italy.

Despite the absence of quantitative data, circumstantial evidences suggesting that the two populations selected for this study are probably the most abundant in central Italy. Nevertheless, density and abundance values are very low in comparison to populations of northern Europe. Our evidences suggest that in Italy *O. eremita* is highly vulnerable, with a high risk of local extinctions. Moreover, the higher dispersal rate and range indicate that the beetles make a greater effort in finding both partners and reproductive sites. This is probably due to the rareness of suitable hollow trees and to the small amount of wood mould inside the cavities.

Along its distribution range, the species seems to show different ecological traits, in relation to population structure, habitat characteristics and dispersal patterns. Mounting evidences suggest that the species status (population abundance and density) improves with latitude, from southern to northern Europe. Probably, the most important factors affecting the status of *O. eremita* are the quality of a single habitat patch (a hollow tree) and landscape characteristics. These two factors, in the last decades, have been mostly driven by change in land use and environmental management, both in forests and agricultural landscapes.

The Mediterranean region is known for its large number of species associated with woodlands compared to central and northern Europe (Blondel and Aronson 1999), and saproxylic beetles constitute a large part of the total biodiversity (Speight 1989). As *O. eremita* was considered an indicator of saproxylic species richness (Ranius 2002) and resulted to be sensitive to habitat fragmentation also in Italy, it could be a useful indicator of areas which are less affected by present or historical fragmentation and thus have a high conservation value. Therefore protecting *O. eremita* and its habitat in Mediterranean woodlands might be essential for long term persistence of biodiversity even globally.

5.2 Implications for conservation

It was estimated that hollows occur in 1% of trees younger than 100 years, in 50% of trees at age of 200-300 years, and in, all trees older than 400-years (Ranius et al. 2009). Therefore, a very long time is necessary to restore this habitat once it has been destroyed. Thus, to preserve hollow trees, environmental awareness and long term management are required.

5.2.1 Finding high priority sites

Monitoring programs to assess the presence of *O. eremita* and its population status are urgently needed all over Italy, also as component of larger management processes. Information about method-specific detection probabilities and costs coming from this study can be used in efforts to optimize study design at large scale.

To manage an area of broadleaf woodland, finding and mapping all the hollow trees should be the first step of a monitoring program with the goal to preserve *O. eremita*. Pitfall traps seems to be the optimal methods to detect the occurrence of this species, as best meets both the needs of efficacy and efficiency. Pitfall traps should be set in as many hollow trees as possible, because there is non-negligible probability to not reveal the presence of the species at the single hollow tree. Traps must be checked at maximum every second day, in order to release individuals without compromising their health or even cause their death. Trapping period in Italy lasts from June to August. However, in order the detect the presence of the species, reducing costs and sampling effort, it should be enough to set the traps between the middle of June and the middle of July, when there is the activity peak of the species.

5.2.2 Management at landscape level

Once the presence of *O. eremita* is confirmed, management authorities should protect the existing hollow trees with large amounts of wood mould, irrespective of tree species. As hollow trees are a habitat with a limited persistence, an urgent task for conservationists is to ensure that sufficient numbers of these trees are maintained continuously in time and space.

When there are problems with age gaps, as a short term strategy, is possible to create artificial habitats, i.e. wood mould boxes (Jansson et al. 2009) or dead hollow trunk with wood mould preserved and kept upright against a tree healthy (Office de Génie Écologique 2009). Instead, as a long term strategy, decay could be initiated prematurely by inoculating wood decaying fungi to start the rot process prematurely or injuring younger trees. For example, chain-saws or explosive could be used to produce shattered trunks or branch stumps which initiate the formation of trunk hollow (Alexander et al. 1996; Cavalli and Mason 2003; Key and Ball 1993), in order to manage the spatial structure of hollow trees during the following two centuries. For a natural microhabitat age continuity, is necessary to plan the recruitment of the next generations of broadleaf trees and the landscape should contain an adequate mixture of young to mature trees that would be allowed to grow on a senescence.

Especially at the southernmost areas, where a single population is widespread on the landscape, with a very low population density, to permit long-term persistence of *O. eremita*, conservation efforts should not focus on preserving few and isolated monumental hollow trees, but should be extended to large stands. In such sites the number of hollow trees should not only be maintained but also be increased, as quickly as possible. In order to reduce the mortality rate during dispersal, both the number of hollow trees and their density must be increased. Our estimates predict that about 62% of the dispersing beetles move distances $\geq$ 150 m, and about 33% more than 250 m. Thus, hollow trees should be concentrated at a distance shorter than 150 m. Even if rarely, the use of shelter place during dispersal and feeding behaviours have been observed in *O. eremita*, therefore as additional conservation actions, restoring shrubs bearing fruits and planting plum and apricot trees at sites where the species is present, could reduce predation risk during dispersing and feeding behaviours.

5.2.3 Management at single tree level

Old broadleaf hollow trees should keep alive for as long as possible, thereby providing time for the new generation to mature and senescence. The amount of wood mould is the primary factor that affects the frequency of occurrence of the species across all its distribution range, and should be more than 4 l per cavity. Cavities

should contain dry or half-moist wood mould rather than wet wood mould, with a low soil contamination. Thus, high cavities should be favoured than the basal ones.

The comparison between southern and northern regions indicated that differences in macro-climatic conditions modify the species' habitat requirements and therefore some conservation measures should be tailored to different local conditions. In northern Europe, it is desirable to maintain or increase the habitat openness to obtain a warm microclimate. On the contrary, in southern regions, it seems that no gain is achieved by increasing the habitat openness.

5.3 Final remarks

Despite considerable efforts are devoted to preserve dead wood and the associated insect fauna of Europe, to allow the long-term persistence of *O. eremita* in Italy, is urgently needed monitoring the species presence starting from all the protected areas with old broad-leaved trees, followed by the habitat management. There is also a need for better knowledge of the autoecology of this species in other Mediterranean environments. If Italian wildlife management does not start to involve considerable efforts to preserve *O. eremita* we should expect many local extinctions for this species in the future, the reduction of its distribution range and the loss of an important genetic heritage.

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LIST OF PUBLICATIONS

Publications in SCI journals

Chiari S., Zauli A., Mazziotta A., Luiselli L., Audisio P., Carpaneto G.M. Surveying an endangered saproxylic beetle, *Osmoderma eremita*, in Mediterranean woodlands: a comparison between different capture methods. Submitted

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