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Osmoderma eremita as an indicator of species richness of beetles in tree hollows

Running head: *Osmoderma eremita* in tree hollows

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Abstract.

The beetle *Osmoderma eremita* has received much attention in the last few years, as it is among those species with the highest priority in the European Union's Habitat Directive. In this paper the species is evaluated as a potential indicator and umbrella species for the endangered beetle fauna in tree hollows. To be useful as an indicator of a species rich fauna it should be easy to inventory and be strongly correlated with the presence of other species. An umbrella species is a species which is so demanding that the protection of this species will automatically save many others. The species richness of saproxylic beetles and occupancy of *O. eremita* were surveyed in tree hollows in an area in southeastern Sweden by assessing presence/absence of living and dead adults (including fragments) and larvae. The species richness was higher when *O. eremita* was present, both at tree and stand level. Several threatened species were associated with the presence of *O. eremita*, whereas others did not correlate with occurrence of *O. eremita*. As *O. eremita* is easy to find and identify, it is useful as an indicator of stands with a rich beetle fauna in tree hollows. *O. eremita* is possible to use as an umbrella species, because if measures are taken to conserve *O. eremita*, many other species in the same habitat are also conserved. However, there are some beetles in tree hollows which seem to be more sensitive to habitat fragmentation than *O. eremita*, and may go extinct if only *O. eremita* is taken into consideration.

Key words: beetles, indicator, *Osmoderma eremita*, tree hollows, umbrella species

INTRODUCTION

Efficient species conservation requires knowledge about how to select areas with the highest conservation value. Regarding insects and other species rich groups, there is usually neither time, economical resources or taxonomic expertise available to carry out detailed inventories for most taxa (e.g. Oliver and Beattie 1996). Selection of the most valuable sites would therefore be easier if these inhabited by a focal species were rich in an entire assemblage of species (so the focal species could be used as an indicator) and if many endangered species occur at the same sites as the focal species but were less sensitive to habitat loss (so the focal species could act as an umbrella species). A biodiversity indicator is usually defined as a group of species which is associated with a high total biodiversity (e.g. McGeoch 1998), but a particular species whose presence is strongly positively correlated with a high species richness in a particular assemblage of species may also be used as an indicator (e.g. Nilsson et al. 1995). An umbrella species is a species which is so demanding regarding habitat quality or density that the protection of this species will automatically save many others (Caro and O'Doherty 1999; Simberloff 1998).

In Europe, saproxylic insects associated with old trees are one of the most endangered invertebrate groups, as their habitat has severely decreased (e.g. McLean and Speight 1993). Many endangered species are strictly associated with trunk hollows in old trees (Martin 1989; Speight 1989). Among these species, the beetle *Osmoderma eremita* has received much attention in the last few years, as it is among those species with the highest priority in the European Unions Habitat Directive (Luce 1996). When sites with *O. eremita* are protected it means that many other organisms associated with old trees, e.g. beetles, flies, lichens and fungi, are also more or less favoured. However, if there are many stands with hollow trees and priority is given to the protection of those inhabited by *O. eremita*, there is no inherent reason why this would mean that the most valuable sites have been chosen.

The aim of this study is to evaluate *Osmoderma eremita* as a potential indicator and umbrella species for the endangered beetle fauna of tree hollows. A number of questions are addressed: is the species richness of saproxylic beetles associated with tree hollows higher in trees and stands where *O. eremita* is present? When the most valuable sites with hollow trees are selected, should presence/absence data on *O. eremita* be used or is it better to rely on the density and physical characteristics of the hollow trees? Are there beetle species associated with the presence of *O. eremita*, and are there species which mainly occur when *O. eremita* is absent? How useful is *O. eremita* as an umbrella species? If measures are taken which ensure its survival, is it reasonable to believe that co-occurring species will also be saved? This research was carried out at a small (per tree) and intermediate (among small stands) scale in hollow oaks in an area in southeastern Sweden.

STUDY AREA AND METHODS

Study area

The survey was performed in a 14 x 15 km wide area around Kättilstad (province of Östergötland, southeastern Sweden, 58°06´N, 15°46´E), where there are many small stands of hollow oaks (mapped in Ranius 2000). The number of hollow oaks has decreased severely in Sweden over the last 200 years (Eliasson and Nilsson 1999). There are historical documents which reveal that the amount of old oaks in the study area has been much higher than today (Anon. 1749). Most of the stands are situated on pasture woodlands which are now used for grazing, but previously were wooded meadows, used mainly for hay-making. At some sites grazing has ceased in the last few decades, which has caused forest regrowth. A few stands with hollow oaks are situated in thin forests on hill-slopes.

I estimated the stand size (= number of hollow oaks with large amounts of wood mould per stand) by visiting all stands with old oaks and searching for hollows with wood mould. Wood mould is loose wood colonized by fungi, often with remains from bird nests and insects. A stand was defined as a cluster of hollow oaks with a distance of <250 m from one tree to another, based on flight distances of up to 190 m found for *Osmoderma eremita* (Ranius and Hedin, 2001). The studied trees were distributed between 41 stands, with totally 1–32 hollow oaks in each. Hollows on the trunks were investigated to decide whether they contained large amounts (several litres) of wood mould or not. I searched for hollow trees by using air photographs and an inventory of old oaks in forest land made by the regional forestry board in 1995.

Methods

Saproxylic beetles were surveyed by searching for larvae and adult specimens including fragments of adult body parts in the wood mould. The sampling was carried out in May and July in 1996. Only beetle species associated with tree hollows (i.e. Groups 2 & 3 according to Ranius & Jansson 2000) were taken into consideration. With *O. eremita*, there is a strong correlation between occurrence of fragments and of living adults and frass from larvae in hollow oaks (Ranius & Nilsson 1997). Also fragments of other larger beetles are easily found and identifiable, e.g. click beetles and Tenebrionids. A comparison of different sampling methods suggests that the fragments accumulate over several years and do not necessarily indicate presence of living adults in the particular year of study (Ranius & Janssson, unpublished). It is not known for how long the fragments persist, but there are circumstancial evidence that they are eaten up by insect larvae and for that reason most of them disappear perhaps within a few years (Ranius and Nilsson 1997). Small species are mainly found as living specimens and are underestimated with this method (Ranius & Jansson, unpublished).

Samples of wood mould were taken from as many hollow oaks as possible.

Sampling was impossible from trees with entrances that were too narrow or too high from the ground (exceeding 7 m) or if the wood mould surface was too deep to reach. From a total of 281 oaks with wood mould, 128 trees were surveyed. Almost all of the studied oaks were alive. There were seven dead but still standing oaks. If there was more than one hollow in a tree, one was randomly selected for sampling. Eight litres of wood mould was sampled. If less than 8 litres was available then as much wood mould as possible was sampled, however 0.5 litre being the minimum sampling volume per tree. The wood mould was sifted and carefully examined for living and dead adult beetles including fragments, and larvae before being returned to the hollow. For each tree, I measured physical characteristics (Table 1) associated with the microclimate and successional stages of the trees (Kelner-Pillault, 1974) which might affect the occurrence of beetles. As the larvae of the study species mostly live deep in the wood mould or in the rotten wood which forms the walls of the hollow it is impossible to carry out detailed studies on their microhabitat without destroying it. I therefore used characteristics that are easy to measure from the outside of the trees and may reflect the successional stage of the decay and the microclimate experienced by the larvae.

The species richness of beetles was analysed in relation to presence/absence of *O. eremita*, size, physical characteristics and density of habitat patches at two scales. First, each tree was treated as a habitat patch and the stand size was taken as a measure of the number of habitat patches. At this scale only those trees were considered where I was able to take an 8 litres sample (95 tree out of 128), in order to avoid differences in sampling efforts between trees. Secondly, on a larger scale, each stand of hollow oaks was viewed as a habitat patch. Then, the number of hollow oaks in neighbouring stands within a radius of 2 500 m was used as a measure of the density of habitat patches. The sampling effort varied between stands, and was approximately proportional to the stand size.

Statistics

The relationship between the number of beetle species associated with tree hollows and presence/absence of *O. eremita* was analysed with t-test. Moreover, I analysed the co-occurrence between *O. eremita* and other species (which were present in at least five trees or stands) by chi-square with presence/absence data of one species at a time.

The number of beetle species associated with tree hollows was analysed with multiple linear regression in SPSS 6.1. At each scale, two different regression models were constructed by stepwise selection (which is a combination of forward selection and backward elimination) of significant variables. One model possibly included physical characteristics, patch size and number of patches of the habitat (Table 1), whereas the other possibly included these variables, and in addition the presence/absence of *O. eremita*. A variable was included in the model at $p = 0.10$ and was removed if that variables significance fell below 0.05.

RESULTS

Species richness was considerably higher in trees where *O. eremita* was present, both at the tree and at the stand level (Table 2) and was higher in trees with a large girth. Stand size was a significant variable at the stand level, but not at the tree level. When the presence/absence of *O. eremita* was included in the models it was a highly significant variable, both at tree and stand level (Table 3 & 4).

The beetle species were either positively correlated or independent on the presence of *O. eremita*, but no species was associated with the absence of *O. eremita* (Table 5 & 6). Only click beetles, Tenebrionids, *Dendrophilus punctatus* and *Liocola marmorata* occurred in frequencies that allowed co-occurrence to be studied. The click beetles *Ampedus cardinalis* and *Procraerus tibialis* often occurred together with *O. eremita*, whereas *A. hjorti* was independent of the presence of *O. eremita*. Among the Tenebrionids, *Allecula morio*, *Prionychus ater* and *Tenebrio molitor* were significantly associated with presence of *O. eremita* (Table 5 & 6). Also with the species significantly correlated with *O. eremita*, a considerable fraction of the findings were from trees where *O. eremita* was absent.

DISCUSSION

Correlations between the number of beetle species, habitat patch characteristics and O. eremita

Presence of *O. eremita* is a better predictor of saproxylic beetle richness than most physical characteristics of the tree measured in this study (Table 2) maybe because many species have similar habitat requirements as *O. eremita* such as that they prefer a stable microhabitat (Ranius and Nilsson 1997). These qualities is difficult to study directly and might be weakly associated with the easily measured physical characteristics used in this study. Another explanation is that the presence of *O. eremita* may influence habitat quality for other species as it changes the physical structure of the habitat. The larvae of *O. eremita* eat large amounts of rot wood causing increases in the volume of the trunk hollow, and their frass is often a dominating fraction of the content of tree hollows (Martin 1993). Thus, *O. eremita* can perhaps be seen a keystone species, which usually is defined as a species whose presence is exceptional in importance in maintaining the diversity of their ecological community (Mills et al. 1993).

Also at the stand level, species richness was strongly associated with the presence of *O. eremita* (Table 3). In the same study area the occupancy of *O.*

eremita has been found to be correlated with mean tree diameter and stand size (Ranius 2000). Thus, the presence of *O. eremita* and species richness are both correlated with the same characteristics of the stands.

Species richness was positively correlated with the diameter of the trunks also in another area (Ranius and Jansson 2000). The correlation between increasing species number and stand size in the present study could be explained by sampling theory alone, as the samples taken per stand increased with the stand size. At the tree level, where the sampling effort was independent of stand size, no such pattern arised.

Osmoderma eremita as an indicator species

Trunks of old oaks may be very species rich and are the habitat for specialized beetles, flies, lichens and fungi (Harding and Rose 1986). Therefore, the conservation of any sites with old oaks would help some species. Today many species seem to have relict distributions which means long-term survival is impossible if the present density of hollow oaks is maintained (e.g. *O. eremita*: Ranius 2000, the pseudoscorpion *Larca lata*: Ranius and Wilander 2000). Therefore, it is not sufficient to preserve the old oaks as they are situated today, but costly, long-term conservation work is needed to increase the quality and size of stands with hollow trees. Habitat restoration efforts are much more efficient for species conservation if they are not carried out randomly in a landscape, but are concentrated to sites adjacent to those occupied by the target species (Huxel and Hastings 1999). Therefore, when restoring habitats with old, hollow oaks we must be able to identify those stands which harbour the most diverse fauna. *Osmoderma eremita* seems to be useful as an indicator, as the species richness of other beetles in tree hollows is considerably higher at sites where *O. eremita* is present.

In Sweden, lists with proposed indicator species have been compiled, and

O. eremita is usually included in these (e.g. Antonsson and Wadstein 1991; Rundlöf and Nilsson 1997; Nilsson et al. 2001). It has also been suggested that the species richness of click beetles living in tree hollows can be used as a biodiversity indicator (Nilsson & Baranowski 1994). As the presence of *O. eremita* is correlated with two vulnerable click beetles, the use of species richness of click beetles and *O. eremita* as indicators might give rise to similar conclusions in many cases. However, this study is carried out on small spatial scales in a region where *O. eremita* seems to be more abundant than in most other parts of northern Europe. In other regions, where *O. eremita* is a great rarity, valuable sites might be overlooked if only *O. eremita* is considered.

It would be attractive to generalize and use *O. eremita* as an indicator species for a wider range of species assemblages. However, several studies suggests that there are few consistent relationships between species richness in different taxa (e.g. Prendergast et al. 1993; Lawton et al. 1998; Jonsson and Jonsell 1999; Uliczka and Angelstam 2000) and therefore it is difficult or impossible to identify groups which indicates overall biodiversity. Regarding saproxylic beetles, sites which harbour a rich fauna associated with tree hollows do not necessarily harbour a rich fauna in other substrates, as the dead-wood habitats are inhabitated by different species assemblages with different requirements (Nilsson et al. 1995).

Osmoderma eremita as an umbrella species

Decision in conservation and management should preferrably be based on information on many species, as it is difficult to ensure that an entire assemblage of species is preserved when only one species is monitored and protected. However, in practical conservation work single species are still important, as they are more likely to be protected by law and they are easier to assess and monitor than groups of species (Martin 1995; Simberloff 1998). For that reason the idea of using umbrella species has arisen. The theory is that measures to protect umbrella species give protection also to less popular and less studied species that may also be threatened.

The umbrella species concept have been used particularly in relation to the conservation of mammals (Wallis de Vries 1995; Noss et al. 1996) and birds (Martikainen et al. 1998). It is however dubious to use mammals or birds as umbrella species when invertebrates are the target species, as the spatial scale of their population dynamics and habitat requirements are very different. *Osmoderma eremita* seems to be unusually suitable as acting as an umbrella species for beetles associated with tree hollows, as it has similar habitat requirements as its target species and the spatial scale of the habitat units relevant for *O. eremita* and the target species is the same (*i.e.* hollow trees). *Osmoderma eremita* is the ecologically most well-studied species among the beetles in tree hollows (Ranius 2000; Ranius 2001a, Ranius and Hedin 2001; Ranius and Nilsson 1997). Therefore it is easier to assess, monitor and protect this species than any other species of this fauna.

The main problem with using *O.* eremita as an umbrella species is probably that the occurrence patterns suggest that some beetles (e.g. *Tenebrio opacus* and *Elater ferrugineus*), however a minority of all species in tree hollows, are more sensitive to habitat fragmentation than *O. eremita* (Ranius 2001b). Therefore, even if measures are taken which are sufficient to preserve *Osmoderma eremita*, there may be other, more sensitive species, which go extinct.

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Table 1. Estimated variables of sampled trees and stands.

Name	Description
A. Individual hollow trees	
Amount of wood mould	The amount of wood mould divided into two categories: small (=0) and large (=1), with about 15 litres as a limit
Aspect (sunshine)	Direction of the entrance in relation to sunshine (treated as a continuous variable: NE = 0; N or E = 1; NW or SE = 2; W or S = 3; SW = 4)
Canopy cover	Unshaded (0), when canopy cover of surrounding trees is <75%, or Shaded (1), surrounding canopy >75%
Entrance	Horizontally (0) or Upwards (oblique/vertical) (1)
Height	Distance between the ground and the entrance hole (m)
Size of the opening	Area of the entrance hole (cm^2) (log transformed)
Stand size	Number of hollow oaks within the stand including the studied tree (log transformed)
Trunk diameter	Trunk diameter at 1.3 m height (m)
B. Stands	

Stand size	Number of hollow oaks within the stand (log transformed)
Density of stands	Number of hollow oaks in neighbouring stands situated within a radius of 2 500 m from the stand (trees within the stand excluded)
Fraction of trees sampled	Number of hollow trees sampled divided by the total number of hollow oaks in the stand
Mean diameter	Mean diameter of the trunks at 1.3 m height of all trees studied in the stand (m)

Table 2. Beetle species richness (excluding *O. eremita*) analysed in relation to presence/absence of *O. eremita* with t-test.

A. In trees (*n* = 95).

O. eremita	*n*	Species number (Mean±S.D.)	*p*
present	33	3.2±1.4	<0.001
absent	61	1.9±1.8	

B. In stands (*n* = 41).

O. eremita	*n*	Species number (Mean±S.D.)	*p*
present	20	6.3±2.4	<0.001
absent	21	2.2±1.7	

Table 3. Multiple linear regression models at the tree level.

A. Coefficient and statistical significance between species richness (log transformed) and characteristics (excluding presence/absence of *O. eremita*) of 95 oaks with wood mould hollows.

	Coefficient	*p*
Trunk diameter	0.31	0.0011
Constant	–0.022	0.846

B. Coefficient and statistical significance between species richness (log transformed) and the characteristics (including presence/absence of *O. eremita*) of 95 oaks with wood mould hollows.

	Coefficient	*p*
Trunk diameter	0.23	0.0158
Osmoderma eremita	0.26	0.0007
Constant	–0.013	0.906

Table 4. Multiple linear regression models at the stand level.

A. Coefficient and statistical significance between species richness (excluding *O. eremita*) and the characteristics (excluding presence/absence of *O. eremita*) of 41 stands with hollow oaks.

Variable	Coefficient	*p*
Stand size	0.64	<0.0001
Mean diameter	0.38	0.0230
Constant	–0.23	0.332

B. Coefficient and statistical significance between species richness (excluding *O. eremita*) and the characteristics (including presence/absence of *O. eremita*) of 41 stands with hollow oaks.

Variable	Coefficient	*p*
O. eremita	0.47	<0.0001
Constant	0.33	<0.0001

Table 5. Beetle species associated with tree hollows and their association with *O. eremita* in 95 oaks. NAME= Species name (taxonomy according to Lundberg (1995)), RED LIST= Red List category according to Gärdenfors 2000 (VU = vulnerable, NT = near threatened), FORM= form of the identified specimens (adults = living adults, larvae = living larvae, fragments = fragments of adults), FREQ.= number of trees with the species present among a total number of 95 trees, O.E. FREQ.= percentage of the trees occupied by the species where *O. eremita* is present, CORR.= Significance level in a chi-square test of the correlation between presence/absence of the species and *O. eremita*. ns, not significant; *, $p<0.05$; **, $p<0.01$; ***, $p=0.001$. All correlations were positive.

NAME	RED LIST	FORM	FREQ.	O.E. FREQ	CORR.
Aderus oculatus		adults	1	0%	
A. populneus	NT	adults	1	0%	
Allecula morio	VU	fragments, adults	32	47%	ns
*Ampedus cardinalis**	VU	fragments	19	58%	*
A. hjorti	NT	fragments, adults	23	35%	ns
Anitys rubens	VU	fragments	1	0%	
Atomaria morio		adults	1	100%	
Batrisodes venustus		adults	3	33%	
Cratarea suturalis		adults	1	0%	
Cryptophagus quercinus	NT	adults	1	0%	
Dendrophilus punctatus		adults	9	44%	ns
Elater ferrugineus	VU	fragments, larvae	3	100%	
Euplectus nanus		adults	1	0%	
Hapalaraea ioptera		adults	1	0%	
Hapalaraea nigra		adults	2	50%	
Hapalaraea pygmaea	NT	adults	1	100%	

Liocola marmorata	VU	fragments	8	50%	ns
Mycetochara axillaris	NT	fragments	1	100%	
Osmoderma eremita	VU	fragments	33	100%	
Oxypoda recondita		adults	3	33%	
Prionychus ater		fragments, adults	25	52%	*
Procraerus tibialis	VU	fragments	30	50%	*
Pseudocistela ceramboides		fragments	2	0%	
Ptinus fur		fragments, adults	4	50%	
Ptinus subpilosus		fragments	1	100%	
Scydmaenus hellwigi		adults	3	33%	
Tenebrio molitor		fragments, adults	36	50%	*
T. opacus	VU	fragments, adults	11	46%	
Trox scaber		adults	2	50%	
Velleius dilatatus	VU	fragments	2	0%	
Xylodromus depressus		adults	2	0%	
Zyras funestes		adults	1	0%	

*) Although some fragments could be identified as either *Ampedus cardinalis* or *A. praeustus*, all those that could be identified with certainty were *A. cardinalis*, and, since *A. praeustus* is not known from oaks in the study areas, all were considered to be *A. cardinalis*.

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Table 6. Beetle species associated with tree hollows and their association with *O. eremita* in 41 stands. NAME= Species name, RED LIST= Red List category according to Gärdenfors 2000 (VU = vulnerable, NT = near threatened), FREQ.= number of stands with the species present among a total number of 41 stands, O.E. FREQ.= percentage of the stands occupied by the species where also *O. eremita* is present, CORR.= Significance level in a chi-square test of the correlation between presence/absence of the species and *O. eremita*. ns, not significant; *, $p<0.05$; **, $p<0.01$; ***, $p=0.001$. All correlations were positive.

NAME	RED LIST	FREQ.	O.E. FREQ.	CORR.
Aderus oculatus		1	100%	
A. populneus	NT	1	100%	
Allecula morio	VU	20	70%	**
Ampedus cardinalis	VU	14	86%	***
A. hjorti	NT	17	53%	ns
Anitys rubens	VU	1	100%	
Atomaria morio		1	100%	
Batrisodes venustus		3	100%	
Cratarea suturalis		1	100%	
Cryptophagus quercinus	NT	1	0%	
Dendrophilus punctatus		7	57%	ns
Elater ferrugineus	VU	1	100%	
Euplectus nanus		1	0%	
Hapalaraea ioptera		1	100%	
Hapalaraea nigra		2	100%	
Hapalaraea pygmaea	NT	1	100%	
Liocola marmorata	VU	9	56%	ns
Mycetochara axillaris	NT	1	100%	

Osmoderma eremita	VU	20	100%	
Oxypoda recondita		3	67%	
Prionychus ater		19	79%	***
Procraerus tibialis	VU	20	70%	**
Pseudocistela ceramboides		5	60%	ns
Ptinus fur		4	100%	
Ptinus subpilosus		1	100%	
Scydmaenus hellwigi		3	67%	
Tenebrio molitor		24	71%	***
T. opacus	VU	3	100%	
Trox scaber		2	100%	
Velleius dilatatus	VU	2	50%	
Xylodromus depressus		2	100%	
Zyras funestes		1	0%	