A protection strategy for the stag beetle (*Lucanus cervus*, (L., 1758), Lucanidae) based on habitat requirements and colonisation capacity

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ABSTRACT

Some of the threatened Belgian populations of the stag beetle are found in a suburban context near Brussels. In this study, a protection strategy is selected based on modelling of the capacity to colonise habitat patches. The habitat requirements were studied and we found that the stag beetle inhabits open woody habitat on steep south-exposed slopes. Two different maps, one with suitable and one with potential habitat were created based on these requirements. Colonisation of habitat patches was modelled to detect best practice for creating corridors between isolated populations and nearby forests. Our results showed that stag beetle colonisation over a period of about 30 years does not exceed a radius of about 1 km. This means that a strategy is required which focuses on in situ protection and the creation of suitable habitat in nearby receptor sites, such as parks.

Keywords: Corridor, stepping stone, log pile, saproxylic beetle

INTRODUCTION

Since the stag beetle, *Lucanus cervus*, was listed in Appendix II of the Habitat Directive a growing number of studies have focussed on this species. The focuses of these studies

vary from purely entomologic interests, for example size variation (Harvey and Gange 2003), to monitoring (Hawes 2008, Fremlin in press), ecology (Rink and Sinsch 2006) and nature conservation (Thomaes et al. 2008b). The ecological data available for this species makes it useful as a model species for conservation research on saproxylic organisms.

In the past, the species was thought to be confined to large woodlands (Tochtermann 1992). However, more recent studies in NW Europe have shown that sag beetles can occur in an open and more urban habitat such as gardens, parks, trees on road verges, sunken lanes, orchards and afforested slopes often in the vicinity of large woodlands (Percy et al. 1999, Sprecher 2003, Smith 2003, Rink and Sinsch 2006, Smit and Krekels 2006). In the north of Switzerland the species needs a mild local climate, while in the south of Switzerland the species is more widely spread (Sprecher 2003). The larvae live about 5 years underground in dead wood of different tree species on loamy or silty soils (Klausnitzer 1995, Pratt 2000). After pupation the beetle will wait nearly a full year before emerging, bringing the length of the total life cycle to 6 years (Klausnitzer 1995).

The stag beetle's distribution in Belgium (based on a 5 x 5km UTM grid map) has previously been explained by five variables: range in elevation, amount of urban area, temperature, soil suitability and amount of broadleaved and mixed forest (Thomaes et al. 2008b). Range in elevation was used as a surrogate for the presence of steep south slopes. Urban areas and forests were selected because they provide the appropriate habitat. The selection of 'urban' in the model could also be explained by the warmer climate, while the current presence of forests could also be important to explain the historic continuity of dead wood (Thomaes et al. 2008b).

Radio-telemetry makes it possible to study the migration of large beetles such as the stag beetle. Rink and Sinsch (2007) followed 56 stag beetles in Germany and concluded that 1% of the males maintain the gene flux among breeding sites within a radius of 3 km. For the colonisation of new sites the dispersal ability of females, which amounts to less than 1 km, is decisive (Rink and Sinsch 2007). Rink and Sinsch (2007) presents probability (P) models for both male, $P=\exp(D/619.6)$, and female, $P=\exp(D/171.9)$, with migration distance (D) from the place of emergence to the place of death, or loss of transmitter, in meters. This study concludes that the stag beetle is strongly limited in its colonisation capacity by the poor flying capacity and limited willingness of the females to fly.

In general, females make a short flight directly after emerging, and after landing they walk while looking for an egg depositing site (Tochtermann 1992, Rink and Sinsch 2007). After egg-laying, a second and even third cycle of flying, walking and egg-laying might occur (Tochtermann 1992, Rink and Sinsch 2007). In a study by Tochtermann (1992), one group of females laid 7 to 12 eggs at one single deposition site; a second group (45%) had a second egg deposition site (17 to 28 eggs for the two sites) while a third group (5%) had a third deposition site (27 to 43 eggs for the three sites). In a study of a 200-year-old non-intervention forest with a continuous population of stag beetles Tochtermann (1992) concludes that 2 females emerge for every successful reproducing female. In captivity he found rates that were 6 to 7 times higher. Tochtermann (1992) does not mention the methodology he used to study the reproduction or how precise his

given data is. It is, for example, known that many beetles are eaten by magpies and crows directly after emerging (for example Smith 2003). It is unclear whether Tochtermann excluded these beetles or not.

In this paper, a selection of the best protection strategy is presented based on modelling the colonisation capacity for suitable habitat patches. This study focuses on a threatened meta-population in a suburban context. The main goal is to look for the best practice in creating corridors between different populations and between populations and nearby forests which can provide appropriate habitat on a larger scale and with better continuity.

METHODS

Study area

For the modelling, a well studied meta-population in the vicinity of Brussels in the Atlantic zone of Belgium was selected. The study area (40 x 20 km), in the loam region of Belgium, consists mainly of suburban area and includes 4 large Natura 2000 forest areas, Halle (550 ha of forest), Sonian (5000 ha), Meerdaal (1300 ha) and Heverlee forest (650 ha). The presence of stag beetles in this area is well studied (Cammaerts unpubl., Thomaes et al. unpubl., Thomaes et al. 2008a), and 26 breeding sites are known (table 1). Breeding sites within less than 3 km from each other are grouped to a single population. The 8 different populations formed in this way are considered to be genetically isolated (based on Rink and Sinsch 2007).

Habitat patches

To determine the habitat requirement I searched for information on the habitat of stag beetle localities in Belgium (Thomaes et al. unpubl., see also Thomaes et al. 2008a, Tho-

Table 1. Different populations with the number of their breeding sites

Population	Number of breeding sites	Figure 3A
Huizingen	1	H
Beersel	1	B
Watermaal-Bosvoorde	7	W-B
Overijse – Jezus-Eik	9	O, J
Tervuren	1	T
Rode Forest	1	RF
Meerdaal Forest - Dijle valley	2	MF, D
Heverlee Forest	4	HF
Total	26	26

maes et al. 2008b). The habitat category that was assigned to a locality was based on: 1) the original observation, 2) a visit to the locality described or 3) a biological validation map (INBO 2007), a polygon map of Flanders and Brussels with the various habitat categories, aerial photos and topographical maps. Method 1 was used for all localities, 2 and 3 only for precisely located places (at least coordinates or street known) with records after 1973. A single locality could be assigned to different habitat categories. The habitat categories were divided into: forest edge, forest, small landscape elements (subdivided into hedges, rows of trees, wooded bank/sunken lanes, orchard), park, artificial breeding heap, urban (mainly gardens and road verges), open agricultural area and unknown/unclear. The distribution over the different habitat categories was compared with the present land use categories of Belgium (ADSEI 2007) omitting the categories water and open natural habitat (dunes, heath and marches) because of the absence of the species in these habitats. The distribution over the different habitat categories was also subdivided for the Atlantic and Continental zones in Belgium and compared with each other, omitting the category open agricultural area because of the low frequency of the beetle in this habitat.

Secondly, the exposition of the slope was determined for every precisely described locality based on topographical maps divided into north-oriented, northeast, east, southeast, etc., or absence of slope or unknown/unclear. For the places located precisely in Flanders and Brussels, the slope inclination was calculated using a digital height model (grid cells 20 x 20m). For all GIS work, ArcMap 9.2 was used.

To outline the habitat patches we intersected a slope map with southwest- to southeast-orientated slopes of ≥4° (see Results) with selected habitat from the biological validation map (INBO 2007). The selected habitat included urban areas with gardens, fields with small woody landscape elements, parks and all oak- and beech-dominated forests regardless of their canopy closure. We excluded urban areas without gardens, agricultural fields without small woody landscape elements, low standard commercial orchards, wet forest types, poplar plantations, pine forests and many other habitats. The slope map acts as a potential habitat map, whereas the intersection of slope and habitat represents a more realistic suitable habitat map.

Colonisation modelling

A prediction of the degree of colonisation was made for the 26 known breeding sites in the study area. As a starting point during the first 6 years it was assumed that 200 females emerged yearly at every breeding site. This number of females was based on a mark-release-recapture study at a medium-sized breeding site in the study area (Cammaerts unpubl.). In this model, it was assumed that all females performed one single migration with a distance calculated using the model of Rink and Sinsch (2007) (see Introduction) and a random direction.

In this model, egg-laying only occurred at the end point of the migration and only if the beetle reached a habitat patch. Six years later, 2 or 5 (depending on the scenario)

new females emerged from the egg-laying spot (based on the data of Tochtermann 1992). From the 7th year onwards only females emerged where successful egg-laying occurred. Because the majority of the females migrated less than 100 meters, the next emerging generation from these females replaced the initial 200 females at each breeding site. The modelling was prolonged for 30 years (5 generations) for the different combinations of habitat patch (suitable and potential) map and number of emerging females (2 or 5), resulting in 4 scenarios.

The results were interpreted by measuring the distance between the original breeding sites and 1) furthest colonisation and 2) furthest areas which were colonised by multiple individuals. Mean values from the different breeding sites of these measurements were calculated and interpreted.

RESULTS

Habitat patches

In total, I was able to define the habitats of 132 stag beetle localities in Belgium, with 160 habitats used in total (Figure 1). The main habitat used was urban, followed by forest, forest edge, small landscape element and park. This was significantly different (x^2-test: p<0.01) from the Belgium land use categories. Urban was the most overrepresented category, while open agricultural was the most underrepresented. The results were
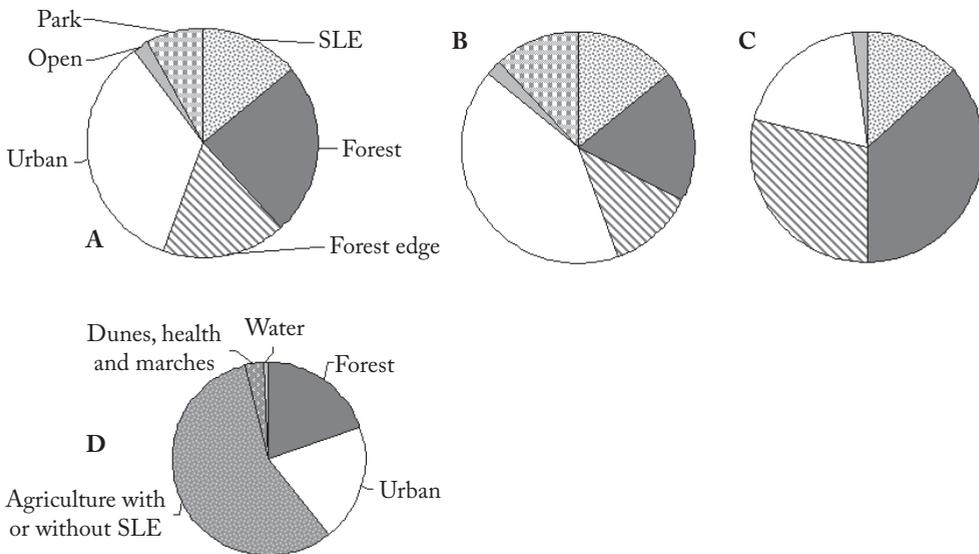

Figure 1. Habitat of stag beetle localities in Belgium (A; n=160), the Atlantic (B, n=108) and Continental (C, n=52) part of Belgium compared with the land use categories in Belgium (D, ADSEI 2007). SLE: Small landscape element.

significantly different between the Atlantic and Continental zones in Belgium (χ^2-test: p<0.01). The habitat used in the Atlantic zone was very similar to the habitats used in the whole of Belgium. In the Continental zone, forest and forest edge became the most important habitats. This zone has a higher forest cover and lower amount of urbanisation compared to the Atlantic part of Belgium.

The habitat found in urban areas was trees and tree stumps in gardens and on road verges, besides numerous breeding sites in railway sleepers (used in gardens), which were used to cover a steep slope. The forest areas where the stag beetle was present tended to be more open forests (Rink and Sinsch 2006, Thomaes et al. 2008a).

The slope orientation and inclination are presented in Figure 2 and based on 116 stag beetle localities in Belgium. 70% of the points lie on a slope with southwest (SW), south (S) or southeast (SE) orientation. Of the 38 localities in Flanders and Brussels 70% are located on a slope between SW and SE with an inclination of ≥4°, however, these slopes cover only 0.7% of the surface of Flanders and Brussels.

Colonisation modelling

The most optimistic scenario regarding colonisation distances was the case where all slopes are considered habitat patches and 5 females emerge for every successful female (Table 2). However, even in this case the mean of maximal distances of multiple colo-
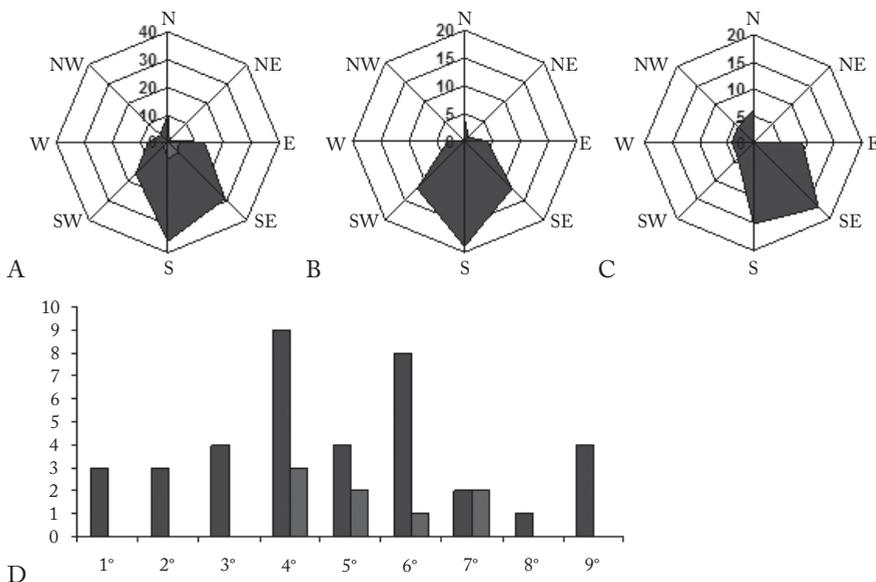

Figure 2. Slope orientation (A-C) and inclination (D) of stag beetle localities (dark grey) and breeding sites (light grey) in Belgium (A; n=116; 20), the Atlantic (B, n=55), Continental (C, n=59) part of Belgium and Flanders and Brussels (D; n=38; 8).

Table 2. Mean (± SD) maximal distances of multiple colonised areas (M) and mean maximal distances of the furthest colonised individual areas (F) in the different scenarios for the next 30 years.

	2 ♀/successful ♀	**5 ♀/successful ♀**
Habitat map = slope	M: 491 ± 223m	M: 940 ± 431m
	F: 829 ± 453m	F: 1420 ± 605m
Habitat map = slope + habitat	M: 385 ± 205m	M: 803 ± 434m
	F: 731 ± 421m	F: 1085 ± 517m

nised areas was only 940 meters, and the mean of maximal distances of singly colonised areas was 1420 meters, both over 30 years (Table 2). For a more realistic scenario (slope and habitat map intersected and 2 females /successful female) these distances were 390 and 730 meters respectively. ANOVA tests of the scenario variables on these distances showed significant effect (p<0.001) of number of emerging individuals, but no significant effect of the habitat map used. In the optimal scenario the beetle dies out in 3 breeding sites, while in the more realistic scenario the beetle disappears at 8 breeding sites. In all scenarios it was impossible to create corridors between the different isolated populations within 30 years or to expand the populations so that the distance between populations became < 3 km.

DISCUSSION AND CONCLUSION

Habitat patches

Based on the results presented here we conclude that the habitat selected is much wider than forests alone, the habitat needs to be at least half open, and contain dead wood, which can, however, also be provided by railway sleepers (cf. Smith 2003) or other artificial dead wood. As in the UK (Percy et al. 1999, Smith 2003), most stag beetle localities are found in urban areas. However, it is feasible that the results are biased by the presence of recorders. Using the localities instead of the original records (like in Percy et al. 1999, Smith 2003) partly counteracts this bias.

In Belgium at least, stag beetles need steep south-exposed slopes on loamy soils. This is because the beetle requires a warm microclimate. Some authors (Whitehead 1993, Pratt 2000, Napier 2003) conclude the same for the UK. Therefore, these slopes are probably less important in southern parts of Europe (Remedios et al. in press). The demand for steep slopes is probably also correlated with soil type, soil moisture or water table. Basically, the species needs a soil that warms up very quickly whether it is provided by a south-exposed slope or a dry sandy soil that warms up faster than a wet loamy soil. It could even be hypothesised that low amounts of dead wood will increase the need for a warmer site. Large amounts of dead wood in natural or semi-natural forests have a higher variety of conditions and therefore a higher chance of being at least partly suitable.

In the habitat patch map, soil type and water table are not included because all steep slopes in the study area have loamy soils, and water tables are deep enough to allow larval development. The patch map does not distinguish between forests with open or closed canopy. The idea was to look for the most efficient corridors and it is assumed that, from a governmental point of view, opening the canopy to create suitable habitat (a large proportion is state-owned forest) is easier than creating or maintaining the habitat in private gardens.

Colonisation modelling

The simplification of the females life cycle to a single migration as described in the methods does probably not limit the comparability of the model to reality. This is because the short life of the adult females is simply structured with, in most cases, a single flight, looking for an egg depositing site, followed by egg-laying (see Introduction). Possibly, the species is capable of following warm micro-sites and/or sensing dead wood rather than following a random direction, but currently there is no proof for such an assumption. Because there is no information on the the species' ability to sense the odour of appropriate dead wood, the model had to assume that the entire area within the habitat patches is suitable for egg laying. Consequently, no conclusions can be drawn from this model regarding the density of stepping stones that are needed to realise the colonisation rates presented here. Based on the limited distances travelled by walking (Rink and Sinsch 2007) we suggest that stepping stones should be in the range of $0.25–1$ ha^{-1} or denser. Stepping stones can easily be provided by building log piles (Tochtermann 1987).

Using migration models from another region is debatable but in this case at least soil, topography, climate and habitat are very similar at both locations (Table 3).

The fact that some of the beetles are eaten directly after emerging is not included in the model. These beetles are mostly excluded from the data of mark-release-recapture, radio-telemetry and probably also reproduction research. Because this model is based on these data it only applies to females which successfully avoid predation

Table 3. Environmental variables of the study region near Brussels compared with the study region Alf-Bullay of the radio-telemetry research by Rink (2006). I: minimum and maximum height (m); II: mean yearly precipitation (mm.y^{-1}); III: mean yearly temperature (°C); IV: mean July temperature (°C) and V: habitat of stag beetles.

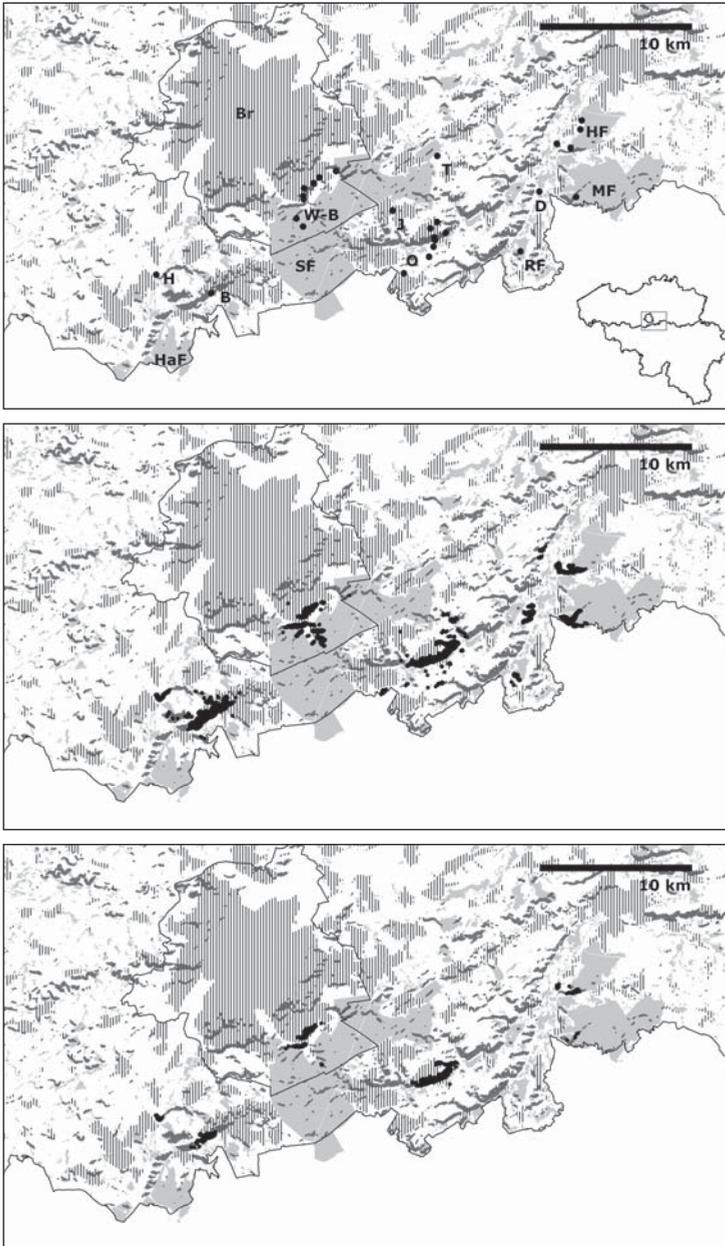|	**Soils**	**I**	**II**	**III**	**IV**	**V**
Brussels	Plateau with loamy soils	10-129	820	10.1	18	Forest edges, small villages and suburban areas
Alf-Bullay	Plateau with clay and loamy soils	94-395	867	9.9	19	Small villages

Figure 3. Maps of the study area with urban (hatched), forest (light grey) and steep south exposed slopes (dark grey). A: 26 breeding sites used in the model (black dots). Abbreviations: Br: Brussels; SF: Sonian forest; HaF: Halle Forest; HF: Heverlee Forest and MF: Meerdaal Forest and for other abbreviations see table 1. B: Modelled colonisation after 30 years (successful individuals as black dots) with the most optimistic scenario (5♀/successful ♀; habitat map = slope). C: Modelled colonisation after 30 years (successful individuals as black dots) with the least optimistic scenario (2♀/successful ♀; habitat map = slope + habitat).

after emergence, and this should not result in a mismatch with reality. Also, males are excluded from the model because they fly more often and therefore do not limit colonisation.

Predictions were only made for 30 years, which is near to many forest planning and management horizons. For longer timelines, assumptions regarding landscape and climate changes become more important. Climate changes, for example, will alter the flying capability of the beetle.

Even if ideal situations are included in the model (5 females /successful female; all slopes considered good habitat), it will not be possible to solve the current genetic isolation of the different populations during the next 30 years within this small study site. Also, colonisation of nearby Natura 2000 forest areas seems to be very limited. Therefore, it is concluded that maximal efforts need to be invested in the in situ protection of the species over the coming decades, even in private gardens. Small landscape elements, local parks, school yards and other local public domains near current breeding sites should be managed so that they form suitable and sustainable habitat for this species. Managers of public areas can best ensure a suitable and sustainable habitat and in this respect have to set an example. Furthermore, it is important to pay special attention to small and isolated breeding sites for which the scenarios predict extinction. At least for the limited areas of Natura 2000 forests which have some chance of being colonised in the coming decades, it is recommended that forest management should open the forest canopy and increase the amount of dead wood on steep south-exposed slopes. This could be done by avoiding replanting after cutting, or waiting at least 10 years, creating permanent open gaps or forest edges with dead wood-rich borders or establishing coppice or coppice with standard (a combination of scattered full grown trees with coppiced shrub; WWF 2004).

REFERENCES

ADSEI (2007) Berekeningen Algemene Directie Statistiek en Economische Informatie op basis van gegevens van het FOD Financiën (Kadaster) en de Algemene Directie Statistiek en

Economische Informatie (Landbouwtelling). Brussels: Algemene Directie Statistiek en Economische Informatie.

Fremlin M (2009) Stag Beetle (*Lucanus cervus*, (L., 1758), Lucanidae) urban behaviour. In: Buse, J., Alexander, K., Ranius, T., Assmann, T. (Eds.) Saproxylic Beetles - their role and diversity in European woodland ecosystems. Proceedings of the 5th Conference on Saproxylic Beetles, Sofia-Moscow: Pensoft, 161-176.

Harvey D, Gange A (2003) Presentation on size variation in the Stag Beetle. In Bowen C. (Ed.) *Proceedings of the second pan-European conference on Saproxylic Beetles, London (UK), June 2002*. London: People's Trust for Endangered Species: 2.

Hawes C (2008) The Stag Beetle *Lucanus cervus* (Linnaeus, 1758) (Coleoptera: Lucanidae): a mark-release-recapture study undertaken in one United Kingdom residential garden. Revue d'Écologie (Terre & Vie), Suppl. 10: 139-146.

INBO (2007) Biological Validation Map: version 2.2. Brussels: Institute for Nature and Forest, GIS-map.

Klausnitzer B (1995) Die Hirschkäfer. Magdeburg: Westarp-Wiss, 109pp.

Remedios E, Méndez M, Lobo J A predictive distribution model for *Lucanus cervus* in the Iberian Peninsula. Abstract volume, *5th Conference on Saproxylic Beetles, Lünenburg (Germany), June 2008*: 20.

Napier D (2003) The great stag hunt: methods and findings of the 1998 National Stag Beetle Survey. In: Bowen C. (Ed.) *Proceedings of the second pan-European conference on Saproxylic Beetles, London (UK), June 2002*. London: People's Trust for Endangered Species: 32–35.

Percy C, Bassford G, Keeble V (1999). Findings of the 1998 National Stag Beetle Survey. London: People's Trust for Endangered Species, 36 pp.

Pratt CR (2000) An investigation into the status history of the Stag Beetle *Lucanus cervus* (Linnaeus) (Lucanidae) in Sussex. Coleopterist 9: 75–90.

Rink M (2006) Der Hirschkäfer *Lucanus Cervus* in der Kulturlandschaft: Ausbreitungsverhalten, Habitatnutzung und Reproduktionsbiologie im Flusstal. PhD thesis, Koblenz-Landau, Germany: Universität Koblenz-Landau, 151 pp.

Rink M, Sinsch U (2006) Habitatpräferenzen des Hirshkäfers *Lucanus cervus* (Linnaeus, 1758) in der Kulturlandschaft - eine methodenkritische Analyse (Coleoptera: Lucanidae). Entomologische Zeitschrift 116: 228-34.

Rink M, Sinsch U (2007) Radio-telemetric monitoring of dispersing Stag Beetles: implications for conservation. Journal of Zoology 272: 235-43.

Smit J, Krekels R (2006) Vliegend hert in Limburg: Actieplan 2006 – 2010. Leiden - Nijmegen: Centraal bureau EIS-Nederland - Bureau Natuurbalans, 97 pp.

Smith MN (2003) National Stag Beetle Survey 2002. London: People's Trust for Endangered Species, 14 pp.

Sprecher E (2003) The status of *Lucanus cervus* in Switzerland. In: Bowen C. (Ed.) *Proceedings of the second pan-European conference on Saproxylic Beetles, London (UK), June 2002*. London: People's Trust for Endangered Species: 6-8.

Thomaes A, Kervyn T, Beck O, Cammaerts R (2008a). Distribution of *Lucanus cervus* (Coleoptera:Lucanidae) in Belgium: Surviving in a changing landscape. Revue d'Écologie (Terre & Vie), Suppl. 10: 147-152.

Thomaes A, Kervyn T, Maes D (2008b). Applying species distribution modelling for the conservation of the threatened saproxylic Stag Beetle (*Lucanus cervus*). Biological Conservation 141: 1400-1410.

Tochtermann E (1987) Modell zur Artenerhaltung der Lucanidae. Allgemeine Forst Zeitschrift 8: 183-84.

Tochtermann E (1992) Neue biologische Fakten und Problematik der Hirschkäferförderung. Allgemeine Forst Zeitschrift 6: 308-11.

Whitehead PF (1993) *Lucanus cervus* (L.) (Coleoptera: Lucanidae) in Worcestershire with a hypothesis for its distribution. Entomologist's Monthly Magazine 129: 206.

WWF (2004) Deadwood - Living Forests: The Importance of Veteran Trees and Deadwood to Biodiversity. Gland: WWF: 15 pp.