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SHORT COMMUNICATION

Timber stacks: potential ecological traps for an endangered saproxylic beetle, the Rosalia longicorn *Rosalia alpina*

Paweł Adamski[1] · Adam Bohdan[2] · Jakub Michalcewicz[3] · Michał Ciach[4] · Zbigniew Witkowski[5]

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Abstract Ecological traps are serious, anthropogenic threats to animal populations. However, in certain cases it is difficult to determine whether they really act in the expected manner. This applies to the harmful effects of beech timber stacked in forests on the endangered saproxylic beetle Rosalia longicorn *Rosalia alpina*, which have been mentioned in numerous scientific articles, conservation action plans and similar publications. The aim of this paper is to determine whether beech timber stacks meet the criteria of an ecological trap for the Rosalia longicorn. Two basic criteria of such a trap are analysed: the attractiveness of timber stacks and the impossibility of complete larval development. The results show that beech timber stacks are highly attractive to Rosalia longicorn imagines. Moreover, the time during which the timber is stacked is shown to be significantly shorter than the species' larval development period. These results suggest that timber stacks can be treated as operative ecological traps for the Rosalia longicorn, even though the extent of their influence on the demographic parameters of this beetle's population has not been estimated. Forest management practices, i.e. increasing amounts and shifts in timing of wood storage, could intensify this threat.

Keywords Ecological trap · *Cerambycidae* · *Rosalia alpina* · Forestry · Timber storage · Biodiversity · Conservation

✉ Paweł Adamski
adamski@iop.krakow.pl

1 Institute of Nature Conservation, Polish Academy of Sciences, al. A. Mickiewicza 33, 31-120 Kraków, Poland

2 Workshop for All Beings, Świętojańska 22/1, 15-082 Białystok, Poland

3 Institute of Forest Ecosystem Protection, Faculty of Forestry, University of Agriculture, al. 29 Listopada 46, 31-425 Kraków, Poland

4 Department of Forest Biodiversity, Institute of Forest Ecology and Silviculture, Faculty of Forestry, University of Agriculture, al. 29 Listopada 46, 31-425 Kraków, Poland

5 Institute of Humanities, Social Sciences and Tourism, Podhale State College of Applied Sciences, ul. Kokoszków 71, 34-400 Nowy Targ, Poland

Introduction

The condition of saproxylic beetle populations is related to forest management practices (Grove 2002; Jonsell 2008; Jurc et al. 2008; Lassauce et al. 2012). One possible forestry-related threat to these insects is the formation of ecological traps (Hedin et al. 2008; Victorsson and Jonsell 2013). An ecological trap is defined as a sink habitat that an organism finds as attractive as, or more so than, another source habitat (Robertson et al. 2013; Gilroy and Sutherland 2007). In other words, it is a situation that arises when the link is broken between the real quality of a habitat and the aspect that persuades an organism to select it (Dwernychuk and Boag 1972; Oaks et al. 2004). The question of an ecological trap usually arises when an organism indirectly assesses habitat quality for reproductive purposes. This happens if the estimation of habitat quality is not based on the presence and abundance of actual resources (e.g. food, shelter), but of other parameters only indirectly correlated with the crucial ones (Gilroy and Sutherland 2007; Kokko and Sutherland 2001; Robertson et al. 2010; Schlaepfer et al. 2002). Ecological traps are now regarded as an important factor endangering populations, and their elimination has become a valid aspect of conservation practice (Mills 2012).

As stored timber attracts saproxylic beetles, its impact on them has been identified as a significant threat factor (Hedin et al. 2008; Nieto and Alexander 2010), leading to a decrease in species diversity and abundance (Jonsell 2008; Lassauce et al. 2012). One of the best known saproxylic species is the Rosalia longicorn *Rosalia alpina* (L.), an endangered beetle protected in Europe, from the family Cerambycidae (Luce 1996; Russo et al. 2011; IUCN 2014; Lachat et al. 2013). Its easy identification, as well as public awareness of broader conservation needs, mean that this insect is regarded as a flagship species of saproxylic biodiversity (New 1997, Russo et al. 2011). The Rosalia longicorn's distribution range covers most of Europe: from the Pyrenees, the Alps, and the Carpathians to Crimea, the Caucasus and the Urals (Sama 2002; IUCN 2008). In the south, it reaches Corsica, Sicily, Greece and the Turkish province of Hatay. In the north, the beetle has experienced substantial retreat, having disappeared from Scandinavia, most of Germany, Poland and the Czech Republic (Slama 1998, Lindheet al. 2010; Michalcewicz and Ciach 2015). Forest management practices are considered to be among the major threats to Rosalia longicorn populations (Drag et al. 2012; Gutowski 2004; Witkowski 2007). That beech timber storage has a highly deleterious effect on this species has been highlighted in both the literature (Drag et al. 2011) and conservation recommendations (e.g. Michalcewicz and Ciach 2012). The Rosalia longicorn lays its eggs on stacked timber, but as this is later transported out of the forest and processed into wood products or firewood, the next generation cannot complete its development. The storage of beech wood in timber stacks located inside or close to the beech forest (within the range of the species' flight capabilities) is spatially and temporally common, so it can significantly reduce a population's reproductive success. Such timber stacks can therefore act as ecological traps for the Rosalia longicorn (Adamski et al. 2013).

The aim of this work is to determine whether timber stacks do indeed fulfil the criteria of an ecological trap for the Rosalia longicorn, an endangered saproxylic beetle. If timber stacks are to act as a genuine ecological trap, two basic criteria must be met: (a) attractiveness:timber stacks attract the beetles, which will remain and/or attempt to reproduce in their vicinity; (b) lack of reproductive success: the development of the next generation in them is impossible or its efficacy is extremely low. In order to define the changes in the extent to which ecological traps occur, we analysed the long-term and intra-seasonal trends in the amounts of beech timber harvested and stored. From the conservation point of view, it is also important to find out whether the mechanism described above does in fact cause a population's condition to deteriorate (Weldon and Haddad 2005).

Materials and methods

The study took place in the Bieszczady Mountains (Carpathians, SE Poland), which lie within the main range of the Rosalia longicorn's distribution in Poland (Michalcewicz and Ciach 2015). The area is mostly covered by forest (81.4%), with fertile Carpathian beech forest *Dentario glandulosae-Fagetum* forming the dominant plant community. The land in the valleys is farmed, meadows and pastures being the dominant form of land use. A characteristic feature of the Bieszczady Mountains is the low altitude of the treeline (ca 1,200 m amsl), consisting of stunted European beeches *Fagus sylvatica* and green alders *Alnus viridis*. Subalpine meadows ("połoniny") lie above the treeline. In 1973, a national park was founded in the eastern part of the Bieszczady Mountains, which currently covers an area of 270.6 km^2. Later, in 1992, two landscape parks were established: the Cisna-Wetlina and San Valley LPs. All three parks are included in the international biosphere reserve that straddles the borders of Poland, Slovakia and Ukraine. There are also a number of small nature reserves in this area (Kondracki 2011). The Natura 2000 site designated PLC180001 Bieszczady was established in the Bieszczady Mountains. The forest stands outside the National Park and nature reserves are managed, mostly by the State Forests National Forest Holding, and are divided into four forestry management areas. Such management includes the harvesting of beech timber.

The attractiveness to the Rosalia longicorn of timber stacks was assessed both indirectly and directly. Indirect assessment was based on an analysis of historical, documented observations of this species from the period 1956–2013 (Adamski et al. 2013; Michalcewicz and Ciach 2015). These observations were divided into two groups: (1) in natural habitats and (2) on stored wood. In order to define the changes in the proportion of observations made in natural localities and in timber stacks, the observations were split into two periods—before and after the year 2000. Although the choice of this boundary date was arbitrary, it is justified by the changes that took place in forestry management around the turn of the century. These included the intensification of forest management, as exemplified by the harvesting of beech timber during the growing season. The differences were assessed using the Pearson Chi-square test (χ^2). Direct assessment was based on visual inspections of timber stacks in the study area in 2012–2015, during the beetle's flight period (June–September). Inspections took place only during the hours around noon (10:00–16:00 h), in conditions favouring a high level of activity of the adult beetles, i.e. warm, sunny weather without rain. The entire area of the timber stack was searched for Rosalia longicorn adults, including single logs and piles of wood. If any were found, their number and behaviour—mating, copulation, oviposition—was noted. No attempts were made to scare away or remove the insects. In all, 96 timber stacks were inspected on 203 occasions (1–4 inspections per stack).

To assess whether these timber stacks were situated in areas important for the Rosalia longicorn based on observations of the species (Michalcewicz and Ciach 2015), the relative density of observations was calculated. The central point of the population core area was determined, as was the standard deviation ellipse (SDE) around it. SDE delineated the area occupied by the core population of the species within the study area (Lee and Wong 2001). In order to illustrate the overlap between the Rosalia longicorn population and timber stack locations, the SDE was pasted on to the map showing the locations of the inspected timber stacks.

The second criterion—the impossibility of completing larval development—was based on timber storage data in the study area. Long-term data on the amount of beech wood harvested in 1997–2015 along with its intra-seasonal dynamics were analysed. The analysis was performed for both year-round harvesting and the amount of beech wood harvested during the Rosalia longicorn's flight period (June–September). We used official data on logging and storing wood volume from the management reports of the forest districts, available from the forest authorities.

Results

66.4% (N = 110) of all the historical records of the Rosalia longicorn in the Bieszczady Mountains were from timber stacks; only 16.4% were from natural localities. Before the year 2000, the fraction of records on stacks was 0.40 (95% CI ± 0.089), while after that year it rose to 0.76 (95% CI ± 0.048), a statistically significant increase ($\chi^2 = 13.16$; df = 3; p = 0.004). Inspections of stacks in 2012–2015 showed the Rosalia longicorn to be present on 13.5% (N = 96) of them. A total of 51 imagines were found during those inspections. 23.5% of these Rosalia longicorn records involved oviposition (7.8% of beetles).

The core Rosalia longicorn population inhabited an area of 543.14 km^2 (Fig. 1A). There was a large degree of overlap between the location of timber stacks and this core area. SDE covered 75% of all timber stacks inspected (Fig. 1B); there were only two records of Rosalia longicorns on timber stacks at the edge of the SDE (Fig. 1B).

The amount of beech timber harvested during the last 19 years increased significantly from 4.57 m^3/ha in 1997 to 10.63 m^3/ha in 2015, exhibiting a clear trend in the intensity of timber production ($R^2 = 0.92$; f = 189.44; p < 0.0001) (Fig. 2a). Moreover, there were significant increases in the percentage of beech timber logged during the summer ($R^2 = 0.65$; f = 31.63; p < 0.0001) (Fig. 2b). This indicates a temporal change in timber production, where nowadays a larger proportion of trees is cut down during the imagines' flight period than in winter: indeed, as much as 50% of beech timber is harvested during the Rosalia longicorn's flight period, far more than used to be the case. The average amount of beech timber harvested during this beetle's emergence period (June–September) was 90.70 m^3/km^2 (SD = 53.28 m^3/km^2). The maximum time for which timber was stacked did not exceed 300 days, and the amount of timber stored for longer than 181 days was minimal (Table 1). However, timber storage practices changed

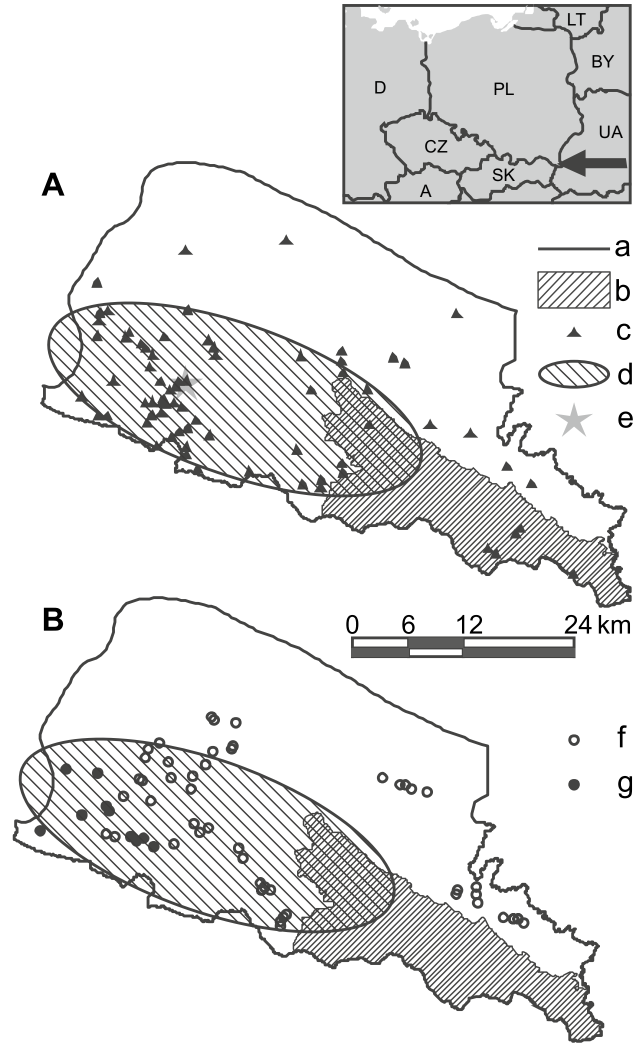

Fig. 1 Distribution of Rosalia longicorn *Rosalia alpina* records in the Bieszczady mountains: **A** records from 2000 to 2012 (Michalcewicz and Ciach 2015), **B** records from timber stacks in 2012–2015, *a* the Polish part of the Western Bieszczady Mountains, *b* Bieszczady National Park, *c* localities of records in 2000–2013 (Michalcewicz and Ciach 2015), *d* standard deviation ellipse of population core area, *e* central point of population core area, *f* locations of timber stacks without Rosalia longicorn, *g* locations of timber stacks with Rosalia longicorn

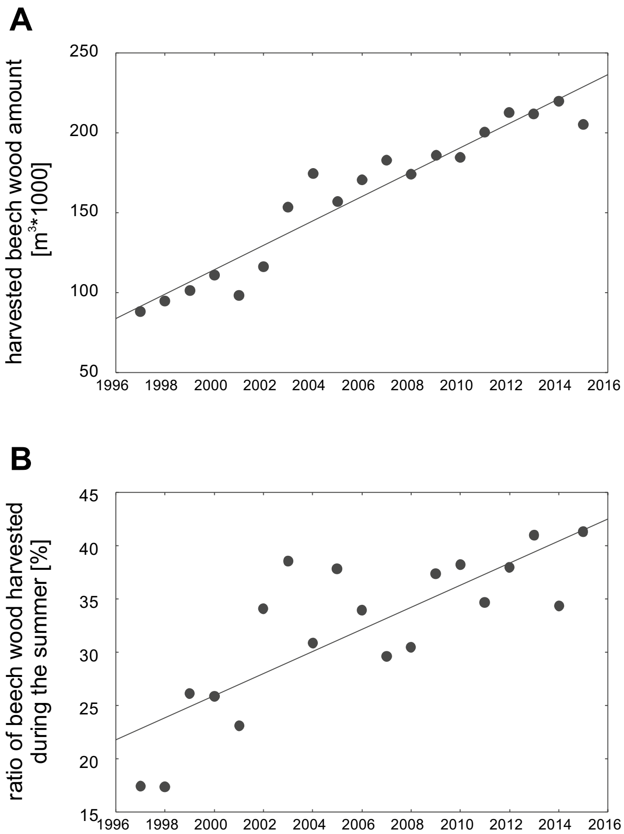

Fig. 2 Changes in the total amount (**a**) of beech timber logged in the Bieszczady Mountains and **b** the harvesting ratio during the flight period of the Rosalia longicorn *Rosalia alpina* (June–September) in the last 20 years. **a**—amount of beech timber harvested, **b**—percentage of beech timber harvested in summer

during the year, the volume of timber in the stacks increasing during the Rosalia longicorn's flight period. Although timber storage for less than 31 days was dominant in all months (including those when the Rosalia longicorn flies), a significant amount of timber harvested between October and May was stored for 31–300 days, making it available to adult beetles (Table 1).

Discussion

Our results indicate that the Rosalia longicorn perceives timber stacks as an attractive oviposition site in Bieszczady; this confirms earlier predictions (Gutowski 2004; Starzyk 2004; Michalcewicz and Ciach 2012) and is consistent with the results obtained by Duelli and Wermelinger (2005). The phenomenon should not be surprising if one takes into account the fact that a large amount of felled timber in a small area acts powerfully on the sensory system of saproxylic beetles (Allison et al. 2004). While the mere presence of insects on timber stacks is not yet proof that they lay eggs on the stored wood, observations of ovipositing individuals make such a hypothesis highly probable. All the available data point to the interpretation that timber stacks satisfy the first criterion of an ecological trap:attractiveness.

The lack of reproductive success is another criterion that can be assumed to be fulfilled. The Rosalia longicorn's life cycle usually takes three years to complete (Gutowski 2004), and no timber stack is left standing for such a length of time. If timber is left in a stack in the forest for more than a year, its commercial value falls, both as a material for processing and as fuel (Alakangas et al. 1999; Ahajji et al. 2009). Also, from the logistical point of view, the best time for timber to be removed from forests in Poland is June–August (Trzciński 2011; Moskalik 2013), which coincides with the Rosalia longicorn's flight period. In effect, the storage of raw timber felled in winter and especially in early spring until its removal in summer can lead to the accumulation of large amounts of potential breeding

Table 1 Average amounts of beech timber harvested and stored in the study area in 2012–2015; numbers in bold indicate wood that would be available to ovipositing females

Month	Harvesting (m^3/km^2)	Storage time (m^3/km^2)			
		<31 days	31–60 days	61–180 days	181–300 days
January	17.16 ± 0.068	10.79 ± 4.275	3.782 ± 3.410	**7.33 ± 4.752**	**0.017 ± 0.0295**
February	23.63 ± 0.055	17.16 ± 4.839	4.44 ± 2.115	**7.04 ± 5.531**	**0.087 ± 0.2525**
March	18.71 ± 0.076	10.81 ± 4.395	7.26 ± 3.501	**5.99 ± 5.706**	**0.200 ± 0.5063**
April	17.68 ± 0.068	9.47 ± 3.725	**3.77 ± 2.684**	**5.56 ± 5.118**	**0.181 ± 0.3009**
May	18.82 ± 0.033	**7.74 ± 3.397**	**2.324 ± 1.319**	**2.88 ± 2.870**	**0.076 ± 0.1800**
June	22.05 ± 0.041	**7.30 ± 2.327**	**0.78 ± 0.773**	**0.89 ± 0.747**	**0.068 ± 0.1740**
July	22.45 ± 0.054	**7.67 ± 2.917**	**1.10 ± 1.352**	**0.68 ± 0.860**	**0.023 ± 0.0413**
August	23.01 ± 0.055	**7.36 ± 3.246**	**1.14 ± 1.011**	**0.40 ± 0.546**	**0.031 ± 0.0545**
September	21.81 ± 0.042	**8.86 ± 3.709**	**1.84 ± 2.030**	**0.49 ± 0.486**	**0.034 ± 0.0764**
October	23.2 ± 0.042	9.97 ± 3.439	2.05 ± 2.102	0.74 ± 0.848	**0.008 ± 0.0242**
November	19.63 ± 0.047	11.64 ± 3.573	4.06 ± 2.869	1.47 ± 1.743	**0.005 ± 0.0190**
December	9.08 ± 0.05	5.13 ± 3.77	6.11 ± 3.000	**3.31 ± 2.857**	**0.001 ± 0.0033**

material before the imagines' flight period. Our results confirm that beech timber stacks are abundant within this beetle's range of distribution and that the timber storage time is shorter than the time required for its complete larval development (Table 1; Fig. 1B).

Nevertheless, the fact that two basic conditions—the attraction of imagines attempting to breed and the impossibility of development reaching completion—does not mean automatically that timber stacks should be regarded as ecological traps. One doubt relates to the degree to which they affect the Rosalia longicorn population. Classical definitions of an ecological trap refer to the concept of a population sink (Delibes et al. 2001; Schlaepfer et al. 2002; Gilroy and Sutherland 2007), but without stating precisely what degree of influence on the whole population justifies the use of the term. Even so, some of the models commonly applied (Kokko and Sutherland 2001; Robertson and Hutto 2006; Robertson et al. 2013) lay great emphasis on this issue. In the case of the Rosalia longicorn population we studied, the fact that the large majority of records of this species come from timber stacks provides concrete evidence supporting the contention that such stacks affect this species to a significant extent. Unfortunately, however, the strength of this argument is seriously undermined by the unstandardized information-gathering methodology. The ready accessibility of timber stacks, the large amounts of wood stored in them and the fact that the stacks are not very tall (and therefore within view of the recorder) mean that discovering the Rosalia longicorn on them is easier than in natural habitats. In the latter, the breeding material may also be scattered and/or be high up in the tree crowns. Such a difference in the detection rate of imagines may have a very significant impact on the results, generating artefacts (MacKenzie and Kendall 2002; Adamski 2004). An accurate assessment of the effect of timber stacks on Rosalia longicorn populations would therefore require the acquisition of precise data on both the state of the entire population and the amount of timber stacked in various parts of the Bieszczady Mountains in the last 50 years. Since such data were never gathered in a methodical manner, assessing the long-term effect of timber stacks on the current species distribution in the study area is practically impossible. Nevertheless, it is a fact that during the last fifty years the Rosalia longicorn's distribution range throughout Central Europe has shrunk dramatically; at present the species' range is limited mainly to mountain areas (Slama 1998; Gepp 2002; Duelli and Wermelinger 2005; Cizek et al. 2009; Drag et al. 2011; Michalcewicz and Ciach 2015; Bussler et al. 2016). This is probably due to the greater inaccessibility of such areas, and consequently the less intensive forest management there. It could also be due to the current practice of stacking timber in the valleys, farther away from the species' localities.

There are other circumstances indicating that the stacking of beech timber could have a deleterious effect on Rosalia longicorn populations. Regardless of the possible waste of reproductive effort due to the impossibility of completing the life cycle, the very presence of imagines at timber stacks—even if they do not attempt to breed—reduces the time they can be present in natural habitats. Given their fairly short lifespan of about one month, this can have an adverse effect on their reproductive success in natural habitats. Moreover, in 2015 certain observations showed that killing is another threat associated with the stacking and export of timber. From one stack, where >30 imagines were swarming, the timber was being removed; this led to the death of at least 12 beetles, which were probably crushed while the timber was being loaded onto lorries (WWF Poland 2015). The possibility of such incidents occurring is due to the increased logging of beeches (Fig. 2a), especially in the summer months (Fig. 2b). Data from 2012 to 2015 show that a considerable amount of timber was left stacked for 30–180 days during the summer months in the study area (Table 1). Since full larval development on stacked timber is not possible, the fact that the timber stacks attracting large numbers of Rosalia longicorn beetles are situated in the area with the greatest number of records of the species suggests that they might be responsible for the population's poorer reproductive success (Fig. 1B).

A further controversial issue is that of habitat quality information as perceived by organisms. Some authors consider that the breakdown in communication between habitat quality and the signals an organism receives to assess this can only be key to the existence of an ecological trap if such a habitat assessment is of an indirect character (Schlaepfer et al. 2002; Robertson and Hutto 2006; Robertson et al. 2013). The classic example in this respect relates to insects that develop in water, which make use of light polarization when ovipositing, as a result of which they will frequently lay their eggs on dry glass or polished granite surfaces (Horváth et al. 2007; Robertson et al. 2010). In the case of timber stacks and the Rosalia longicorn, the assessment of attractiveness is indirect: the stored timber could provide appropriate conditions for larval development, were it not transported out of the forest and processed. On the other hand, the presence in a forest of large amounts of dead wood which remains there at most for 12–15 months, can be classified among Human-Induced Rapid Environmental Changes (Sih et al. 2011), an important factor in ecological trap formation (Robertson et al. 2013; Sih et al. 2015). It is also worth stressing that, despite the above reservations, the term "ecological trap" is on occasion also used to describe situations where the habitat signal is indirect (Cayuela et al. 2015). The mechanism by which saproxylic insects are attracted to timber stacked in forests could be one such situation (Hedin et al. 2008).

Summarizing, we can state that stacks of beech timber in forests satisfy the basic criteria for being an ecological trap with respect to the Rosalia longicorn beetle. The lack of accurate, long-term demographic data precludes a reliable estimate of their influence on the whole population of this beetle and its long-term trend, however. Nevertheless, because of the high level of threat to this conservation priority species, and the increasing numbers of trees being felled at all times of the year, it would be advisable to refrain from stacking timber in or near localities of the Rosalia longicorn.

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