Standardized pheromone-based toolboxes of saproxylic indicator species guiding European conservation efforts?

Mattias C. LARSSON & Mikael A. MOLANDER

Department of Plant Protection Biology, Swedish University of Agricultural Sciences, P.O. Box 102, 230 53 Alnarp, Sweden (e-mail: mattias.larsson@slu.se, mikael.molander@slu.se)

Abstract

One of the major obstacles for evidence-based conservation of saproxylic insects is the lack of reliable data regarding distributions and population trends, which makes it difficult to properly identify and address causes behind species declines. At present, efficient pheromone-based monitoring is possible for a limited number of rare and threatened saproxylic insects for which pheromones have been identified. When efforts will be made to expand the number of model systems available for conservation monitoring, the question is how to select and apply limited sets of saproxylic indicator species to provide the best possible feedback for coordinated long-term conservation efforts at larger scales. We suggest that pheromone monitoring of standardized sets of saproxylic insect species could provide toolboxes with great general validity for proactive conservation efforts on a regional and sometimes pan-European scale. We also discuss which specific characteristics of model species that should be considered when composing standardized monitoring systems designed to capture a broad spectrum of landscape factors of conservation concern, with some examples from published and ongoing studies.

Keywords: Biodiversity, Insects, Landscape ecology, Pheromones, Monitoring.

Introduction

One of the major obstacles for evidence-based insect conservation is the lack of reliable data regarding distributions and population trends of rare and threatened species. This is especially true for many saproxylic insects, which can be very difficult and resource demanding to monitor with traditional methods. Over the last decade, a growing number of studies have exploited the legendary attractiveness of insect sex pheromones to monitor rare and threatened insects including many saproxylic species, providing the possibility to perform population monitoring with unprecedented spatial and temporal accuracy over large geographic regions (LARSSON, 2016).

Thus far, pheromones have only been available for a limited number of species with conservation concern, as the identification of new pheromones constitutes a severe bottleneck for developing monitoring systems for additional species. Substantially expanding the number of species for pheromone-based conservation monitoring should preferably be accompanied by a strategy for selecting suitable model species. Within the EU, the designation of species of especially high priority for conservation within the habitat directive (ANONYMOUS, 1992) tends to limit the focus given to other potential indicator species that could provide valuable information. Providing an alternative selection of species supported by the scientific community working on saproxylic insects, which could serve as general models and indicators for saproxylic insect conservation efforts across the EU, backed by efficient pheromone-based monitoring systems, may increase the prospect of funding for the identification of new pheromones. Many saproxylic species of conservation concern are found over most or all of Europe, although their conservation status may vary substantially between regions. We suggest that the development of a common standardized toolbox of pheromone monitoring systems for saproxylic species, which could be applied as a whole or in part throughout most of Europe, would be of great benefit for coordinated long-term conservation efforts within the EU. Coordinated monitoring

efforts using the same model species would provide comparable reliable data across many habitat and climatic variables, which would be invaluable for developing models for how these variables interact to determine species distribution. Here, we discuss some relevant parameters that influence the distribution of saproxylic species in the landscape, and how model species may be included to cover all these parameters in a common toolbox.

Substrate dynamics: Covering all the bases

The aim of successful conservation management is ultimately to provide enough deadwood substrate for the persistence of a broad spectrum of saproxylic species. Different species will exhibit vastly different demands with regards to the type of substrates they prefer. However, we can classify different deadwood substrates according to the successional dynamics of their generation and decomposition (Fig. 1). Different types of deadwood substrates will be available at various stages as trees mature, with thin branches and small trunks appearing first, whereas large-diameter trunks and branches, and large tree hollows, typically appear only as the tree is sufficiently mature or senescent (RANIUS *et al.*, 2009). Likewise, every type of substrate has a specific persistence or longevity with regards to their suitability for certain guilds of saproxylic insects. Freshly dead branches or logs of any diameter are only suitable for one or two seasons for many species that colonize the nutrient-rich cambium under the bark. Conversely, tree hollows forming inside living trees, or large, decaying logs that persist for a long time, may be suitable for many years or decades for other guilds of saproxylic species.
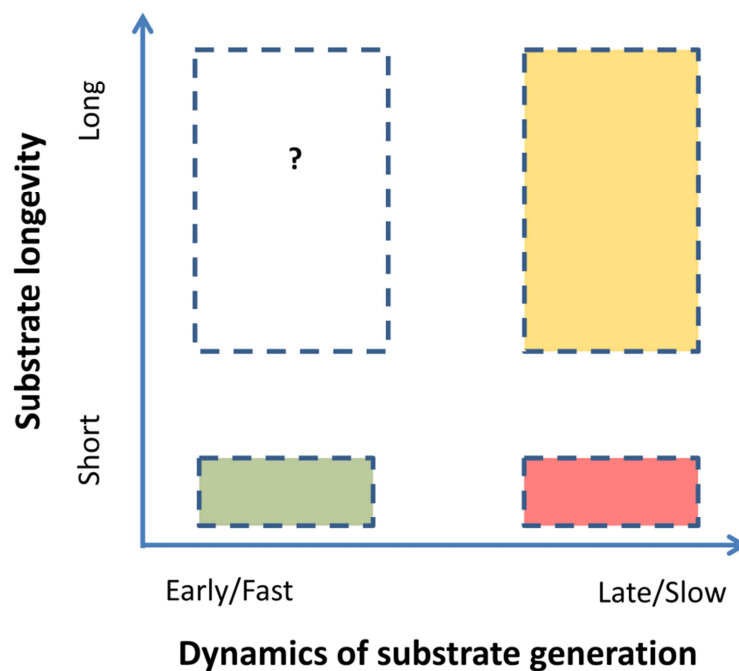

Fig. 1. Characterization of saproxylic substrate resources according to two successional parameters: The X axis represents the successional time it takes for substrates to form, whereas the Y axis represents how long the substrate may typically last in the present stage once formed. The boxes represent the specific combinations of parameters relevant to individual species or guilds of species. It is doubtful to what extent fast-forming yet very durable substrates even exist, but if so, their associated species would probably be of least concern for conservation. With some exceptions, species dependent on fast-forming substrates with high turnovers may reasonably be expected to be less vulnerable than species dependent on slow-forming substrates, given the present state of substrate dynamics in forests. Many slow-forming substrates are rather durable, however, providing a certain degree of resilience for many late-successional species as long as their habitats are not destroyed or degraded. Species dependent on late-successional substrates with high turnover should be exceptionally sensitive given the present stage of many forests.

158

The vulnerability of saproxylic species should in principle be related to how well their habitat requirements are adapted to the local dynamics of substrate turnover. Relatively minor proportions of species specializing on early successional habitats should be vulnerable even in rationally managed, modern forest landscapes, as these have the potential to provide sufficient amounts of substrates. However, there are examples of rationally managed forest landscapes that exhibit even low amounts of early-successional deadwood materials. As these materials are usually relatively short-lived as suitable substrates, early successional species are dependent on a frequent supply of new substrate. Many late-successional species should be more vulnerable, in comparison, as late-successional habitats are less frequently allowed to develop in modern managed forests. Forests or individual trees that exhibit late-successional qualities often represent only isolated fragments in the landscape. On the other hand, many of these late-successional habitats have comparatively high durability and may be suitable for the same species during relatively long periods, thus providing a certain degree of resilience and long-term refuge for these species. Some species that utilize substrates that are both late in the successional generation and have short persistence could be expected to contain a high proportion of vulnerable species, as this combination makes for a very limited and intermittent supply of substrates.

A suitably composed portfolio of model species should include representatives from all these combinations of habitat parameters, in order to capture a wide range of parameters related to substrate dynamics. Previous efforts using available pheromones have mainly focused on a few species, which constitute the first conservation species of saproxylic insects for which pheromones have relatively recently been identified. These model species have been associated with old and relatively persistent habitats, such as the commonly used model species *Osmoderma eremita* (Scopoli) and *Elater ferrugineus* L. in tree hollows (CHIARI *et al.*, 2013b; MUSA *et al.*, 2013; ZAULI *et al.*, 2014). We have recently expanded the range of relatively late-successional model species under study with two species of longhorn beetles associated with large-diameter trees and logs, for which pheromones are available (BARBOUR *et al.*, 2011; RAY *et al.*, 2012): the root-feeding generalist *Prionus coriarius* L. and the pine-feeding *Tragosoma depsarium* L. Preliminary studies have demonstrated that, much like the previously studied species, these two species also appear to be tightly linked to sites with long-term continuity of their late-successional substrates.

As a complement to these late-successional species we have recently started studying a handful of early-successional longhorn species with one-year life cycles and fast substrate dynamics connected mainly to oak and other deciduous trees: *Pyrrhidium sanguineum* L., *Poecilium alni* L., *Poecilium pusillum* (Fabricius), *Phymatodes testaceus* (L.), *Plagionotus arcuatus* L. and *Xylotrechus antilope* (Schönherr). In Sweden, these species range from common species of no conservation concern to red-listed (VU) species, and thus form an interesting complex of model species for comparative studies of their vulnerability to substrate dynamics in a landscape context. We have just started landscape studies to determine the responses of these model species to substrate resources provided by management actions like thinning and logging.

In a Swedish context, the presumably most vulnerable group of saproxylic beetles, connected to rare, late-successional substrates with fast turnover, could be exemplified by the longhorn beetle *Plagionotus detritus* (L.). In Sweden, this species appears to be exclusively using large-diameter branches, logs, and tree trunks as larval substrate. These resources are only rarely formed, by means of shedding of very large branches or death of relatively mature trees, and they are soon spent. This means that sufficient amounts of substrate can only be continuously generated at sites with very large numbers of oaks of sufficiently mature age. Consequently, *P. detritus* has suffered catastrophic decline over the last decades, with apparent losses of almost all previous Swedish populations. Based on a newly identified pheromone, we recently have started monitoring this species in relation to targeted management actions to reverse its decline.

Host specificity

Most threatened saproxylic species are either generalists for conifers or deciduous trees, or associated to one or a few of the dominant types of trees and associated fungi that can be found in the major European forest biomes. Providing pheromone monitoring systems for a handful of characteristic saproxylic model species for each dominant tree species would go a long way towards a standardized

set of indicators that could capture much of the successional dynamics in European mixed-forest ecosystems.

Shade tolerance

Various species or guilds of saproxylic insects differ to a great extent in what degree of shading they tolerate or prefer. Lack of management of many open woodland or wood pasture areas leads to generally closed tree canopies, and to increased ingrowth of bushes and younger trees that shade out trunks and canopies of veteran trees, which may lower their vitality and cause their death. Shading of larval substrates may also make them uninhabitable or less preferred by many saproxylic species, which may contribute to the severe shortage of certain types of larval substrates. Managing the degree of shading is therefore a very important component of conservation forest management. In our landscape studies of both early-successional and late-successional species we perform extensive comparisons between trapping in open and shaded habitats, to determine the sensitivity of different species to shading. Our trapping studies of *T. depsarium* and *P. coriarius* suggest that the former species is sensitive to shading of its larval substrate (see also WIKARS, 2004), whereas the latter is often trapped in forests under comparatively dense canopies. Consequently, *T. depsarium* appears to be far less resilient to this kind of landscape change, even though both species exploit late-successional substrates of comparable durability.

Dispersal ability

Dispersal ability of a species is a crucial component in its ability to adapt to landscape destruction, fragmentation and isolation (RANIUS, 2006). Previous studies of dispersal ability in late-successional hollow-tree-species like *O. eremita* and *E. ferrugineus* (HEDIN et al., 2008; SVENSSON et al., 2011; ZAULI et al., 2014) frequently demonstrated limited dispersal ability, especially in Scandinavian populations. We are now complementing corresponding studies of dispersal in longhorn beetles with both slow and much faster substrate dynamics, based on mark-recapture studies with pheromone traps. Based on limited studies of observed dispersal events, some species of longhorn beetles adapted to early-successional substrates with fast dynamic turnover exhibit very high dispersal propensity.
Based on landscape-wide monitoring in fragmented forest patches, representative species from all saproxylic groups that we have studied so far have exhibited gaps in their distribution among adjacent and isolated habitat patches, suggesting that they may be limited by dispersal and colonization ability on a population level (LARSSON, 2016).

Climatic factors

Most of the factors listed above are themselves heavily influenced by climatic factors. Several insect species of high conservation concern in Northern Europe and Scandinavia are common, and sometimes even considered pests, in Central or Southern Europe. These differences may be due to climate influences on host or substrate specificity, with many species exhibiting broader preferences in their ranges of hosts and successional stages at more Southern latitudes. Some species, notably *O. eremita*, also exhibit much greater dispersal propensity and dispersal distances in Southern Europe (CHIARI et al., 2013a; ZAULI et al., 2014). Likewise, many species appear to be more sensitive to shading at more Northern latitudes with colder climate. Using the same set of trapping systems in different climate zones provides a possibility to directly study how different parameters interact with climatic factors.

Validity of generalization from few model species

With only a limited number of species used as references for processes affecting whole forest communities, it is highly relevant to ask whether these species actually capture sufficient information to warrant this narrow range of focus. Studies both with and without pheromones suggest that some species indeed appear to be good indicators for the presence of other species utilizing similar habitats (RANIUS, 2002; JANSSON et al., 2009; SEBEK et al., 2012; ANDERSSON et al., 2014). However,

transferability of indicators between regions may be questioned (JANSSON et al., 2009), along with the whole indicator concept (SAETERSDAL & GJERDE, 2011; GAO *et al.*, 2015).

One major advantage of using standard toolboxes of model species for monitoring will be to provide an understanding of how different variables interact and influence species distributions across large geographic ranges. We should also remember that the primary objective of these monitoring toolboxes is not to study correlations between different groups of biodiversity, but to characterize long-term quantitative measurements of population change in response to conservation efforts. The increased resolution offered by targeted pheromone monitoring of relatively few species may be preferable to the uncertainty offered by stochastic survey methods, which may have relatively limited power to detect true responses.

References

ANDERSSON K., BERGMAN K.O., ANDERSSON F., HEDENSTRÖM E., JANSSON N., BURMAN J., WINDE I., LARSSON M.C. & MILBERG P., 2014. - High-accuracy sampling of saproxylic diversity indicators at regional scales with pheromones: the case of *Elater ferrugineus* (Coleoptera, Elateridae). *Biological Conservation*, 171: 156-166.

ANONYMOUS. 1992. - Directive 92/43 of the Council of the European Community on the conservation of habitats and wild fauna and flora. European Community, Brussels

BARBOUR J.D., MILLAR J.G., RODSTEIN J., RAY A.M., ALSTON D.G., REJZEK M., DUTCHER J.D. & HANKS L.M., 2011. - Synthetic 3,5-dimethyldodecanoic acid serves as a general attractant for multiple species of *Prionus* (Coleoptera: Cerambycidae). *Annals of the Entomological Society of America*, 104 (3): 588-593.

CHIARI S., CARPANETO G.M., ZAULI A., ZIRPOLI G.M., AUDISIO P. & RANIUS T., 2013a. - Dispersal patterns of a saproxylic beetle, *Osmoderma eremita*, in Mediterranean woodlands. *Insect Conservation and Diversity*, 6(3): 309-318.

CHIARI S., ZAULI A., MAZZIOTTA A., LUISELLI L., AUDISIO P. & CARPANETO G.M., 2013b. - Surveying an endangered saproxylic beetle, *Osmoderma eremita*, in Mediterranean woodlands: a comparison between different capture methods. *Journal of Insect Conservation*, 17(1): 171-181.

GAO T., NIELSEN A.B. & HEDBLOM M., 2015. - Reviewing the strength of evidence of biodiversity indicators for forest ecosystems in Europe. *Ecological Indicators*, 57 420-434.

HEDIN J., RANIUS T., NILSSON S.G. & SMITH H.G., 2008. - Restricted dispersal in a flying beetle assessed by telemetry. *Biodiversity and Conservation*, 17(3): 675-684.

JANSSON N., BERGMAN K.O., JONSELL M. & MILBERG P., 2009. - An indicator system for identification of sites of high conservation value for saproxylic oak (*Quercus* spp.) beetles in southern Sweden. *Journal of Insect Conservation*, 13(4): 399-412.

LARSSON M.C., 2016. - Pheromones and other semiochemicals for monitoring rare and endangered species. *Journal of Chemical Ecology* DOI: 10.1007/s10886-10016-10753-10884.

MUSA N., ANDERSSON K., BURMAN J., ANDERSSON F., HEDENSTRÖM E., JANSSON N., PALTTO H., WESTERBERG L., WINDE I., LARSSON M.C., BERGMAN K.-O. & MILBERG P., 2013. - Using sex pheromone and a multi-scale approach to predict the distribution of a rare saproxylic beetle. *PLoS ONE*, 8(6): e66149.

RANIUS T., 2002. - *Osmoderma eremita* as an indicator of species richness of beetles in tree hollows. *Biodiversity and Conservation*, 11(5): 931-941.

RANIUS T., 2006. - Measuring the dispersal of saproxylic insects: a key characteristic for their conservation. *Population Ecology*, 48(3): 177-188.

RANIUS T., SVENSSON G.P., BERG N., NIKLASSON M. & LARSSON M.C., 2009. - The successional change of hollow oaks affects their suitability for an inhabiting beetle, *Osmoderma eremita*. *Annales Zoologici Fennici*, 46(3): 205-216.

RAY A.M., BARBOUR J.D., MCELFRESH J.S., MOREIRA J.A., SWIFT I., WRIGHT I.M., ZUNIC A., MITCHELL R.F., GRAHAM E.E., ALTEN R.L., MILLAR J.G. & HANKS L.M., 2012. - 2,3-Hexanediols as sex attractants and a female-produced sex pheromone for cerambycid beetles in the genus *Tragosoma*. *Journal of Chemical Ecology*, 38(9): 1151-1158.

SAETERSDAL M. & GJERDE I., 2011. - Prioritising conservation areas using species surrogate measures: consistent with ecological theory? *Journal of Applied Ecology*, 48(5): 1236-1240.

SEBEK P., BARNOUIN T., BRIN A., BRUSTEL H., DUFRENE M., GOSSELIN F., MERIGUET B., MICAS L., NOBLECOURT T., ROSE O., VELLE L. & BOUGET C., 2012. - A test for assessment of saproxylic beetle biodiversity using subsets of "monitoring species". *Ecological Indicators*, 20: 304-315.

SVENSSON G.P., SAHLIN U., BRAGE B. & LARSSON M.C., 2011. - Should I stay or should I go? Modelling dispersal strategies in a threatened saproxylic beetle, *Osmoderma eremita*, based on pheromone capture and radio telemetry. *Biodiversity and Conservation*, 20: 2883-2902.

WIKARS L.-O., 2004. - Habitat requirements of the pine wood-living beetle *Tragosoma depsarium* (Coleoptera: Cerambycidae) at log, stand, and landscape scale. *Ecological Bulletins*, 51: 287-294.

ZAULI A., CHIARI S., HEDENSTRÖM E., SVENSSON G.P. & CARPANETO G.M., 2014. - Using odour traps for population monitoring and dispersal analysis of the threatened saproxylic beetles *Osmoderma eremita* and *Elater ferrugineus* in central Italy. *Journal of Insect Conservation*, 18(5): 801-813.