LIFE NATUR' ADAPT

A META-ANALYSIS ON THE INFLUENCE OF THE CESSATION OF FOREST LOGGING ON BIODIVERSITY

Abstract :

Drawing on the systematic review method, a meta-analysis was conducted on the consequences of abandoning logging (i.e. human logging) on biodiversity (*Langridge et al., In prep*). This meta-analysis was carried out as part of the LIFE Natur'Adapt project, to support managers in their choices when writing adaptation plans.

A first study was published in 2010 on European forests (*Paillet et al., 2010*), showing that the abandonment of logging decreases the diversity of vascular plants and increases the diversity of saproxylic beetles (feeding on decaying wood). Here, the meta-analysis has been extended to the whole world, considering boreal, temperate and Mediterranean forests. It confirms previously obtained results and also indicates (and this is a novelty) that the differential in species diversity between non-harvested and harvested forests tends to increase with the length of time since harvesting stopped when the forest is located in a humid climatic context, and to decrease in a dry context.

Our meta-analysis also highlights the lack of studies on certain taxa, and the inadequacy of the «species richness» indicator alone in analyzing this problem, insofar as it does not reflect biodiversity as a whole and ecosystem functionality.

To remember : The effects of abandoning logging vary from one taxonomic group to another. In forests that are no longer exploited, species richness is lower for vascular plants and higher for fungi in the broad sense. The climatic context influences the direction and speed of dynamics after logging has ceased. Further studies are needed, both to reach conclusions on other taxa and to go beyond species richness alone.

Langridge J., Delabye S., Gilg O., Paillet Y., Reyjol Y., Sordello R., Touroult J., Gosselin F. (*In prep*). Nature strikes back: biodiversity recovery after forest management abandonment in the world's boreal, temperate, and Mediterranean forests. An evidence-based approach.

Paillet Y, Bergès L., Hjältén J., Ódor P., Avon C., Bernhardt-Römermann M., Bijlsma R.J., Bruyn L. de, Fuhr M., Grandin U., Kanka R., Lundin L., Luque S., Magura T., Matesanz S., Mészáros I., Sebastià M.T., Schmidt W., Standovár T., Tóthmérész B., Uotila A., Valladares F., Vellak K., Virtanen R. (2010). Biodiversity Differences between Managed and Unmanaged Forests: Meta-Analysis of Species Richness in Europe. Conservation Biology 24, 101–112. https://doi.org/10.1111/j.1523-1739.2009.01399.x

1. Background

As part of the European LIFE Natur'Adapt project, three management measures were studied through bibliographic syntheses (map and systematic review, meta-analysis) in order to better understand how these measures can be used to adapt the management of protected areas to climate change. The «free evolution» of natural environments is one of the three measures studied. The notion of free evolution is still the subject of debate as to its definition[1] [2]. Here, our question focused specifically on the effects of halting logging (timber harvesting) on biodiversity (fauna, flora and fungea). In other words, given a stand that has been logged in the past, is it better for biodiversity to continue or abandon logging?

Also, recent studies indicate that old-growth* and mature* forests can improve the resistance and resilience of ecosystems to the effects of climate change. Forests that have not been logged for a long time are said to have greater structural complexity, with specific species assemblages that favor certain biotic interactions, which could be an asset in the face of climate change. However, there is a need to know whether the same applies to the cessation of logging in previously logged stands, with a view to so-called «passive» restoration. This is what our study addresses here, by analyzing the local biodiversity of forests following the cessation of logging and in relation to climatic variables.

We already have some answers to this question. The free evolution of a forest is in fact synonymous with a greater «anthropic naturalness*» of the environment[3]. Studies carried out in northern European countries (Sweden, Finland, Norway) show a clear relationship between the exploitation of the environment and the impoverishment of mushroom communities. For European forests in general, *Paillet et al (2010)* conclude that bryophytes, lichens, fungi, saproxylic beetles and carabid beetles show a significantly higher species richness in non-harvested forests. The opposite is true for vascular plants, whose richness is higher in logged forests.

The cessation of logging favours specific forest substrates such as dead wood (standing or on the ground) and old trees, which has a positive impact on the diversity of saproxylic beetles, fungi and lichens © DSOREL

1 - François Sarrazin, Jane Lecomte, Nathalie Frascaria-Lacoste. Libre évolution des forêts, de quelle évolution parle-t-on ?. Revue forestière française, AgroParisTech, 2022, 73 (2-3), pp.401-416. https://hal.archives-ouvertes.fr/hal-03637720/document

2 - Denis Couvet, Hélène Soubelet, Aurélie Delavaud, Agnès Hallosserie (2022). « Libre évolution » : de quoi parle-t-on ?. https://www.fondationbiodiversite.fr/libre-evolution-de-quoi-parle-t-on/

3 - Gosselin, F.; Génot, J. C.; Lachat, Thibault (2021) Libre évolution et naturalité en forêt : définitions et métriques associées. In : Revue Forestière Française, vol. 73, n° 2-3, p. 115–136. https://revueforestierefrancaise.agroparistech.fr/article/view/5464

2. Method

This meta-analysis was inspired by the original meta-analysis by *Paillet et al. (2010)*, while making methodological improvements, such as: (i) a broader scope by considering boreal, temperate and Mediterranean forests on a global scale; (ii) a focus on forests that are no longer exploited, but have been historically exploited, in order to adopt a clearer perspective in terms of the potential of management abandonment as a restoration tool ; (iii) a contextualization by climate variables included in the models, notably to match the objective of Life Natur'Adapt; (iv) a more complete treatment of data pseudo-replication* - notably by excluding pseudo-replicated comparisons.

This work was based on the systematic review method proposed by the *Collaboration for Environmental Evidence*[4]. Using keywords, a bibliographic search was carried out on 2 databases («Scopus» and «Web Of Science Core collection») and 1 search engine (Google Scholar). The documents collected were sorted successively by title, abstract and full text, to ensure a set of articles relevant to the meta-analysis sought. The quality of the selected studies was assessed to determine whether or not they should be included in the meta-analysis. In the end, our corpus was made up of 170 studies, 131 of which measured specific richness and 39 abundance.

3. Main results

	Specific richness	**Abondance**
Number of studies	131	39
Location	Mainly in Europe (78) then Asia (28) and North America America (24)	North America (22), Europe (14), and Asia (3)
Taxons	Flora (68) Fauna (24): 14 birds, 12 arthropods other than beetles, fungea (20) and lichens (16)	Mostly animals (23 birds and 9 insects) and more rarely vascular vascular plants (7)
Forests	Temperate (59) boreal (62) and more marginally Mediterranean (10)	More boreal forests (26) than temperate forests (11) and very few Mediterranean forests (2)

Overview of the literature obtained after the sorting and critical analysis phases

4 - For more information on this method, see the systematic reviews presentation note.

Analysis of species richness (131 studies)

The results of the meta-analysis on species richness tend to confirm the results of the *Paillet et al. (2010)* meta-analysis in terms of taxonomic group responses.

They show that vascular plants have a significantly lower richness (-17%) in forests where logging has been abandoned. This seems logical, since the cessation of management tends initially to favour the closure of the environment, and thus to disadvantage the plant species of clearings and edges, which form a very diverse group of species in the forest. On the other hand, for saproxylic beetles, the opposite trend was observed, with a higher species richness after the logging was stopped (+29%).

The application of another statistical model, taking into account the time elapsed since logging ceased and rainfall, clarifies these results, with an increase in species richness for fungi in the broad sense (including lichens) (18%) and a decrease for plants in the broad sense (including bryophytes; -11%); the longer the time elapsed since logging ceased, the greater the increase in species richness in the wettest sites (see box on climatic factors), the opposite being true in the driest sites.

Abundance analyses (39 studies)

The results of the meta-analysis on abundance were inconclusive due to the small number of publications.

Focus on a French study *Toigo et al (2013)*: «Does stopping logging matter more than habitat characteristics for carabid beetles?»

This study analyzed beetle species richness in 6 forest sites located in France, comparing reserves that had not been logged for at least 20 years and extensively logged forests (without clear-cutting and slash transport).

The results show that greater basal area and humus activity are favorable to the richness of forest carabid beetles, particularly as humus is a food source for forest beetles. More unexpectedly, however, this study shows that openland beetles and specialist forest beetles are primarily favored by the cessation of logging. In the case of open forest species, this may be explained by the fact that the horizontal structure of unharvested forest is actually more heterogeneous than that of harvested forest.

Overall, total beetle richness and the richness of four groups in particular (forest species, winged beetles, moisture indifferents and carnivores) is greater in unlogged forests, but their variations are primarily linked to the effects of forest structure and humus, factors that are relatively uncorrelated with logging abandonment.

For a more comprehensive overview, see the report on the «Forest Management, Naturalness and Biodiversity» group in issue no. 80 of Rendez-vous Techniques de l'ONF : https://www.onf.fr/+/13b::rendez-vous-techniques-de-lonf-no-56.html

Lessons learned and discussion

The results show that different taxonomic groups react differently to the cessation of logging. Based on our dataset, vascular plant richness is significantly lower in forests that are no longer logged than in those that are still logged, the reverse being true for saproxylic beetles. When precipitation and post-logging time are included in the model, the diversity of fungi in the broad sense (including lichens) appears higher in forests that are no longer logged, while plants in the broad sense (including bryophytes) remain systematically more diverse in forests that are still logged.

A number of mechanisms may explain these results. Changes in stand age and structure, vertical stratification, tree species composition and disturbance regime may play a role in determining the differences between unlogged and logged forests. These factors affect light, temperature, water availability, litter decomposition and upper soil conditions, which can strongly influence the presence of plants and fungi in forest habitats.

For vascular plants, in logged forests, artificial features such as roads, ditches and/or logging tracks are important sources of moderate disturbance that promote the availability of resources, e.g. light and nutrients, for vascular plants. In addition, some logging practices (e.g. selection logging, retention logging) induce small-scale disturbance that can result in greater environmental heterogeneity than intensive conventional logging, creating canopy openings, litter removal and soil disturbance. These factors are known to favor understory vascular plants and promote the richness and cover of shade-intolerant forest species in early succession. It should be noted, however, that the opening up of these environments is naturally ensured by herbivores, notably medium-sized mammals[5], but even more so by large mammals (elk, bison, aurochs, etc.), now extinct in most European forests. Extensive forest management therefore seems to represent a certain substitute for the incompleteness of our forest ecosystems, provided that elements favouring forest biodiversity (large trees, dead trees, microhabitats) are preserved during management.

Conversely, the diversity of saproxylic beetles, fungi and lichens depends on specific forest substrates such as dead wood (standing or on the ground) and old trees - favored by non-harvesting[6] - which may explain the positive impact of halted harvesting on the richness of these communities. Fungal communities such as decomposers are an important group of habitat specialists that depend on decaying logs.

5 - Boulanger, V, Dupouey, J-L, Archaux, F, et al. Ungulates increase forest plant species richness to the benefit of non-forest specialists. Glob Change Biol. 2018; 24: e485– e495. https://doi-org.proxy.mnhn.fr/10.1111/gcb.13899

6 - Paillet, Yoan & Pernot, Coryse & Boulanger, Vincent & Debaive, Nicolas & Fuhr, Marc & Gilg, Olivier & Gosselin, Frédéric. (2015). Quantifying the recovery of old-growth attributes in forest reserves: A first reference for France. Forest Ecology and Management. 346. 51-64. https://doi.org/10.1016/j.foreco.2015.02.037

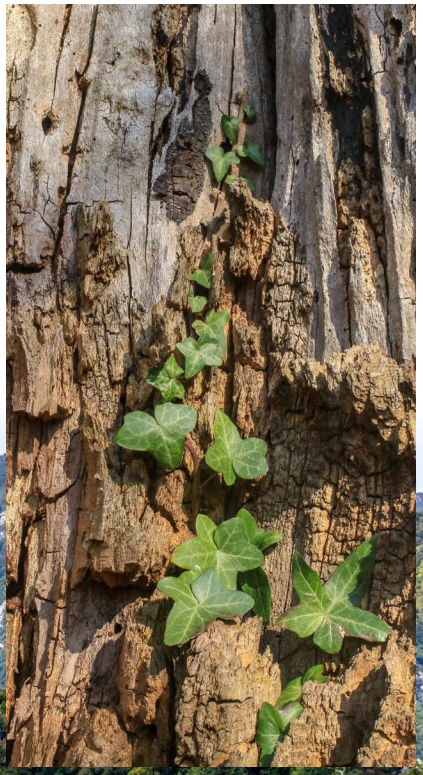
The length of time since logging ceased and the amount of precipitation are both important. The longer the time elapsed since logging was abandoned, the greater the specific richness of fungi in the broadest sense (including lichens) in the wettest sites © DSOREL

Focus on climatic factors

One of the original features of this work is the inclusion of climatic variables in the analysis, notably precipitation, in order to assess whether the effect of the cessation of logging on biodiversity is influenced by the climatic context.

We found that average rainfall does indeed have a significant positive impact on the temporal dynamics of species richness between forests that are no longer logged and those that are. In this case, in humid climates- annual precipitation above 966 mm- differences in species richness between forests no longer logged and those still logged increase over time since logging ceased, whereas they decrease in dry climates. In other words, the dynamics of species richness after logging abandonment is positive in humid climates, whereas overall, post-logging delay "alone" shows no significant effect on resilience, and in dry climates the opposite trend is observed.

This interaction between post-outage delay and precipitation can be explained by at least two mechanisms. Firstly, higher precipitation accelerates decomposition processes, increasing the availability of late-stage decomposed substrates and thus favoring the return of taxonomic groups dependent on them. Secondly, drier climates are accompanied by increased fire risks, which can reduce the development of late successional stages in the landscape as time passes since logging was abandoned- inducing a "faster" disturbance regime in unlogged forest than in logged forest.



The effects of abandoning logging vary according to taxonomic group. Unlike saproxylic beetles, vascular plant richness is significantly lower in forests no longer logged than in those still logged. DSOREL

4. Limitations and prospects for improvement

Although our study covered the whole world, the majority of the studies selected ultimately concern European forests. In addition, the Mediterranean biogeographical zone is very much in the minority in our corpus compared with boreal and temperate zones (for example, no studies on bryophytes, fungi or lichens in Mediterranean forests). In addition, certain taxonomic groups are largely under-represented, if not totally absent from our documentary base, notably among vertebrates (mammals, amphibians, reptiles and, to a lesser extent, birds), but also among insects, arachnids, molluscs and crustaceans. A lack of published knowledge is therefore evident. This gap could be filled by new studies to be planned.

Furthermore, most of the studies retained after selection measured species richness, highlighting a lack of studies on abundance. It should be pointed out that we did not direct our bibliographic search towards studies with more complex biodiversity measurements. Another limitation of this work is that we only have results on local species richness, commonly referred to as «alpha*» diversity. Admittedly, this is a simple and practical measure to use, measured in numerous studies, but it does not reflect changes in composition (between unharvested and harvested forest) or the variability of species assemblages between plots.*

We should also point out the lack of information in the articles concerning the age of the forest, site conditions or management history, which made it difficult to carry out a critical analysis to correctly assess the level of bias in the publications, nor any possible difference in behavior between more homogeneous groups of species.

Finally, our results need to be put into perspective. Forests that are no longer exploited, and to which we have compared exploited forests, have nevertheless been modified by man in the past. They are therefore not virgin forests. Thus, our work sheds light on the potential impact on local biodiversity of the decision to stop logging in a forest whose wood has been exploited up to now, but does not provide elements of comparison with forests that have never been impacted by man. It would therefore be interesting to examine this subject in greater depth by considering complete forest ecosystems, never exploited, as reference sites, in order to see whether the reintroduction of certain species (e.g. large herbivores) is not preferable to management, including extensive management, or even to the cessation of exploitation, in order to achieve this state of naturalness.

Glossary

Ancient forest : Forest established on land where woodland continuity has existed for several centuries.

Mature forest : Forest characterized by the presence of large trees, old trees and dead trees, both standing and on the ground, marking advanced stages in the forest's biological cycle.

Old Growth forest : Forest that is both old and mature, and has therefore been little or not exploited for several decades or centuries.

Anthropogenic naturality : A state of complete (or almost complete) absence of human disturbance for a certain period of time, which may also correspond to non-management (no intervention). The notion of anthropic naturalness can be restricted to a type of human disturbance (e.g. logging): for example, some of the forests studied here were not logged, but may still have been hunted. If the ecosystem has been managed in the past, the metrics used to describe this naturality are therefore focused on past harvesting (e.g. duration since last harvest, intensity of past harvesting, etc.).

Pseudo-replication: Repeated sampling in the same treated plots produces pseudo-replicates, which are not statistically independent, unlike true replication.

«Alpha» diversity : Alpha diversity corresponds to the number of species co-existing in a given environment (site), whereas beta diversity corresponds to a comparison of taxon diversity between ecosystems (regions).

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