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SYSTEMATIC REVIEW PROTOCOL Open Access

Does post-disturbance salvage logging affect the provision of ecosystem services? A systematic review protocol

Alexandro B Leverkus[1*], Lena Gustafsson[2], José María Rey Benayas[3] and Jorge Castro[1]

Abstract

Background: Forest fires, insect outbreaks, and windstorms are common forest disturbances that are expected to increase in importance in coming decades. Post-disturbance management often involves salvage logging, i.e. the felling and removal of the affected trees. However, harvesting these biological legacies may represent a second disturbance whose effects on ecosystem processes add on those of the initial disturbance. Many of the potentially affected processes, such as soil erosion and stream water quality, represent regulating and supporting ecosystem services important for human society. In the last 15 years, much empirical evidence has been gathered on the ecological consequences of this management practice, and it has now become necessary to synthesise this evidence in meaningful ways for managers and decision-makers.

Methods: With this systematic review we aim to synthesise the literature on the effects of salvage logging on ecosystem services and determine the effects of major effect modifiers such as disturbance type and intensity, the timing and method of logging, and the type of forest. We will conduct searches of the primary scientific literature, which will be selected and categorised according to its relevance to the topic and its quality. Each relevant article will be read in full to obtain the necessary data for meta-analysis and to identify its main conclusions. Mixed-effects models will be performed to assess the effects of the identified effect modifiers on the effect sizes of the salvage intervention on ecosystem services and to account for random effects arising from studies being performed in the same area. Sensitivity analyses will test the potential effects of study quality, and publication bias will be assessed with the trim and fill method. We will present the results as a narrative review and a meta-analysis.

Keywords: Fire, Functioning, Insect infestation, Management, Regeneration, Salvage harvesting, Windthrow

Background

Strong, discrete forest disturbances such as wildfires, insect outbreaks, and storms leave behind large amounts of biological legacies, including snags and patches of surviving vegetation [1]. As such disturbances have increased and are predicted to further increase in quantity, affected surface area, and severity in the coming decades [2–4], there is a need to identify and adopt management strategies that favour the functioning and regeneration of post-disturbance forests. The most common post-disturbance management approach in many parts of the world is salvage logging, i.e. the widespread felling and removal of the affected trees [5, 6]. However, there is increasing evidence that the biological legacies remaining after disturbance, including burnt trees and branches, can play a critical role in forest recovery [5–9].

Despite the widespread application of salvage logging after forest disturbances, this practice is surrounded by controversy arising both from the main motivations for it and from other unaccounted effects. Advocates for salvage logging argue that it reduces the risk of pest outbreaks and wildfire due to the elimination of substrate and fuels. Salvage logging also intends to recover some of the economic value of the affected wood. The simplified post-logging habitat structure, resulting from the

*Correspondence: leverkus@ugr.es
[1] Departamento de Ecología, Facultad de Ciencias, Universidad de Granada, 18071 Granada, Spain
Full list of author information is available at the end of the article

removal of fallen trunks, should ease subsequent forestry activities such as reforestation. Finally, there is a social perception of ugliness and death that may be offset by removing the affected elements. However, these arguments are not based on scientific evidence but rather on traditional practices, perceptions and deductions. A report published in 2000 [5] reviewed the ecological effects of salvage logging and identified a lack of research on this topic. This review triggered a wide number of empirical studies around the world, and in the last 15 years all of the above-mentioned motivations for salvage logging have been questioned (e.g. fire risk [8] and forestry and economics [10]), and many other effects have been described [5, 6]. It has been found that the effects of salvage logging may differ from those of traditional logging or disturbance alone due to the accumulation of disturbance events (i.e. the original disturbance and logging) followed closely in time [11].

As previously summarised [11], the impacts of salvage logging may be categorised as affecting: (a) the physical structure of ecosystems (as derived from the definition of salvage logging); (b) particular elements of the biota and species assemblages (these have recently been quantitatively reviewed by Thorn and colleagues, 2015, u. review); and (c) key ecosystem processes and services. Ecosystem services are the benefits that people obtain from ecosystems, and they are categorised into provisioning (e.g. food, timber), regulating (e.g. climate regulation, water purification), cultural (e.g. recreational, spiritual), and supporting services (required for the functioning of the other types of services, e.g. soil formation and nutrient cycling) [12]. Salvage logging may impact ecosystem services through affecting processes such as soil erosion and hydrological regimes [13], nutrient cycling [14], carbon sequestration [15], seed dispersal [16], tree regeneration [17], resistance to invasive species [18], and many other processes [5–7, 11, 19]. However, studies often report contradictory results, and so far there is no comprehensive, quantitative review of the ecosystem processes and services that may be affected by salvage logging. The present review aims to fill this knowledge gap and to reduce some of the uncertainty surrounding many of the ecological effects of salvage logging. Although these effects are often context-specific, a global review that accounts for potential reasons for heterogeneity among observed responses could aid managers and policy-makers worldwide to decide whether salvage logging is likely to enhance the recovery of the values and processes of disturbed forests under their local conditions.

Objective of the review

The objective of this review is to summarise the large amount of existing information on the effects of salvage logging on different aspects of the functioning of post-disturbance forest ecosystems, including a quantitative meta-analysis. Our experience and interaction with forest managers led to the formulation of the main research question in a meaningful way for non-academic stakeholders, i.e. in terms of ecosystem services or the benefits that human society obtains from ecosystems. Thus, the main objective of the review is to answer the following primary research question:

Does post-disturbance salvage logging affect the provision of ecosystem services?

This question implies the following key elements:

- Population: Forests affected by one of the following disturbances: storms, insect outbreaks, or fire.
- Intervention: Salvage logging, i.e. the harvesting of trees from areas after disturbance events (definition modified from [11]). Different methods of extraction and degrees of intervention will be explicitly considered.
- Comparator: Control areas are either (1) forests after disturbance where no subsequent salvage logging is conducted or (2) disturbed forests prior to salvage logging.
- Outcome: Ecosystem services = regulating and supporting services only. Examples include pollination, seed dispersal, carbon sequestration, biological control/pest regulation, water purification, climate regulation, natural hazard (e.g. flood or subsequent fire) regulation, erosion control, invasion resistance, and air quality maintenance (this list will be modified according to what is available in the literature). For most ecosystem services we will use variables considered an indicator or proxy for an ecosystem service (e.g. the quality of stream water, the abundance of seed dispersers, or the amount of fuel). Provisioning services such as timber are excluded because they are tightly linked to market conditions, which can considerably vary across locations and time. We also exclude cultural services because we expect little to non-existent quantitative studies on this topic.

We expect heterogeneity in the answer that individual studies provide to the primary research question and in the direction and magnitude of the effect. Thus, we will search for the reasons underlying this heterogeneity. Specifically, as secondary research questions we will ask:

Does the response of ecosystem services to post-disturbance salvage logging vary with the:

(a) Kind and intensity of the disturbance?
(b) Biome/geographic region?

(c) Intensity, method, or timing of salvage logging?
(d) Time after salvage logging?
(e) Execution of post-disturbance actions besides salvage logging (e.g. planting)?
(f) Kind of study design?

Different kinds of ecosystem services may also be affected in different ways by salvage logging. Thus, we will ask another secondary question:

Do different kinds of ecosystem services respond in different ways to salvage logging?

The response to these questions will be interpreted and discussed in terms of (a) the impact of salvage logging on ecosystem functioning and human wellbeing, and (b) the potential factors that could mitigate the negative effects of salvage logging.

Methods

Literature searches

The initial literature search will be conducted in English in the Web of Science with the aim of answering the primary research question. The terms will be searched in titles, abstracts and keywords and will be based on the Disturbance and the Intervention. The results will not be date-restricted but will be limited to the fields of Environmental Sciences and Ecology/Forestry/Biodiversity Conservation/Zoology/Plant Sciences/Meteorology and Atmospheric Sciences/Entomology/Water Resources.

To find other publications, including grey literature, complementary searches will be performed with simplified Disturbance and Intervention terms. These searches will be made in the Directory of Open Access Journals (https://doaj.org/) and the CABI database of forest science (http://www.cabi.org/forestscience/).

Specific searches will be conducted using the websites of the Canadian Forest Service (http://cfs.nrcan.gc.ca/publications) and US Forest Service (http://www.treesearch.fs.fed.us/).

Searches using Google Scholar, also including Disturbance and Intervention terms, will be made in English, Spanish, and German, and the first 100 hits will be screened.

As complementary bibliographic searches, the reference lists of relevant articles will be screened, and articles citing them will be searched in the Web of Science to complement the list. If necessary, authors of relevant articles will also be contacted to clarify study designs or provide additional data. A list of the publications will be sent to all the authors of the review here proposed and to other experts in the field to assess its completeness.

Initial scoping exercise

A preliminary search was performed on 9 March 2015 in the Web of Science. The initial terms considered were:

(a) Disturbance terms = (disturb* OR wildfire OR fire OR windthrow OR storm OR pest ((insect* OR beetle*) AND (outbreak OR attack)))
(b) Intervention terms = (salvag* OR logg* OR harvest*)
(c) Outcome terms = (ecosystem OR environment* OR pollin* OR dispers* OR carbon OR sequestr* OR sink OR pest OR invasive* OR water OR purif* OR climate OR weather OR waste OR flood* OR erosion* OR air)

Searching the Disturbance terms alone yielded 416,471 hits. Searching Disturbance + Intervention terms (strings joined with the Boolean operator AND) resulted in 25,664 hits. A further search including Disturbance + Intervention + Response terms still yielded an excessive 17,580 hits. Thus, after this preliminary search we refined the intervention terms to include only logging that happens after disturbance, i.e. "salvage logging", "salvaging", or post-(fire/disturbance/…) logging/harvesting:

Intervention terms = ((salvag* OR post*) AND (logging OR harvest*))

This search provided 1,423 hits. As the list of ecosystem services needs to be refined according to what is found in the literature, it would be desirable to obtain a comprehensive list of the studies on salvage logging to avoid missing any study. Thus, after eliminating the restrictions resulting from the inclusion of Outcome terms, we got 1,845 hits. After screening some titles and obtaining suggestions during peer review we decided to include the terms "snag remov*", "cutting" and "felling" in the Intervention terms. In this way, on 5 June 2015 we obtained a total of 5,039 hits.

Search string

After the scoping exercise described above, the final search string used is as follows:

(disturb* OR fire OR wildfire OR windthrow OR storm OR pest ((insect* OR beetle*) AND (outbreak OR attack)))
AND
("snag remov*" OR ((salvag* OR post*) AND (logging OR harvest* OR cutting OR felling)))

Study inclusion criteria

To be considered for the review, studies must be empirical and fulfil all of the following inclusion criteria:

(a) Relevant population: forest after one of: fire, insect outbreak, or storm disturbance (including both natural and anthropogenic causes).
(b) Relevant intervention: salvage logging.
(c) Relevant comparator: disturbed forest without (or prior to) salvage logging.
(d) Relevant outcome: response variable that can be regarded as and indicator or used as a proxy of a regulating or supporting ecosystem service.

Modelling and review articles will be recorded as additional materials.

Article screening

The relevance of the articles resulting from the literature searches will be assessed through a stepwise elimination procedure. The articles will be screened in the following steps:

1. All the titles will be read in the first step, and articles with irrelevant titles will be discarded. This step will be carried out in a conservative way to avoid discarding any potentially relevant publications, so that in doubt of the relevance of an article it will be kept (e.g. articles on post-fire ecosystem dynamics will be saved, as they might include salvage logging as a factor without it being reflected in the title). Before screening all the titles, two members of the review team will screen a subset of titles and the difference in outcomes will be assessed through a kappa test. If necessary, the inclusion criteria will be discussed again prior to screening all the titles. Kappa tests will also be conducted in steps 2 and 3 below.
2. The abstracts of articles with relevant titles will be read in the second step, and articles with irrelevant abstracts will be discarded. To be classified as relevant in this step, the abstracts must fulfil all of the inclusion criteria (a), (b), and (c). If in doubt about the relevance of a publication, it will be kept for the next step.
3. The articles with relevant abstracts will be read in full. At this stage, articles failing to fulfil one of the study inclusion criteria will be discarded. To find studies that fulfil inclusion criterion (d), the main objectives of the studies will be assessed as well as the study-site descriptions (including tables and figures). Relevant articles will be categorised according to the study quality assessment criteria defined below. A list of articles excluded at this stage, together with the reason for exclusion, will be provided as additional material.

Study quality assessment

The retrieved studies that pass the above steps of article screening will be appraised (1) to decide on their inclusion in the narrative part of the synthesis and/or the meta-analysis on the basis of their susceptibility to bias, and (2) to consider possible lines of action among included studies to minimise the effect of potential bias in the original studies on the conclusions of the review. For this, the studies will be included in one of the following three broad categories (which may be revised according to the standards found in the retrieved literature):

1. Empirical studies with treatments applied at appropriate spatial scales and with replication (at least three replicate units) will be used for the meta-analysis and the narrative synthesis. We will perform sensitivity analyses to test for the potential effects of study quality. For example, we expect many studies to make use of areas where the intervention was applied for silvicultural rather than experimental motivations, thus lacking randomisation, and sensitivity analyses will aim to show whether including or excluding such studies yields similar results. Other characteristics to be noted for each study and considered for sensitivity analyses will be whether the methods are clearly stated and repeatable (including a clear description of the disturbance and the salvage intervention) and confounding factors are properly dealt with.
2. Empirical studies with experimental flaws—e.g. due to the lack of replication—may be included for the narrative synthesis only.
3. Empirical studies whose conclusions are compromised due to strong experimental flaws will not be considered for the review.

Potential effect modifiers and reasons for heterogeneity

We expect heterogeneous responses to our primary research question. Variation in site characteristics, disturbance properties, salvage logging practice, and response variables/measurements across studies should lead to considerable differences in the direction and magnitude of effects. The main potential effect modifiers (or covariates) have been identified according to the reviewer team's knowledge of the subject and are listed below under "Data extraction strategy". However, this list is not necessarily exhaustive, and new modifiers may be added during the process of acquisition and classification of publications. The existence and magnitude of the effect of these modifiers will be quantitatively assessed through meta-analytical statistics.

Data extraction strategy

The following information from the relevant literature will be extracted and stored in Excel spread sheets. The title, journal, author, year, and methodological approach of all the relevant articles will be stored in one file. Another file will include the data for quantitative analysis. Each row will constitute one data point, and several data points might arise from a single study (e.g. due to 2 years of sampling). The columns will contain the numerical data for the response variable in intervened and control areas (mean, standard deviation, and number of replicates) as well as the meta-data (which will be assessed as effect modifiers). For the numbers obtained for the response variables we will always take care of potential pseudoreplication, i.e. subsampling that does not constitute true replication. The meta-data will include:

- Study site (which will be used as a random effect in mixed effects models)
- Country
- Forest biome (according to [20])
- Forest type (conifer, broadleaf, mixed)
- Disturbance type (fire, windthrow, insect outbreak)
- Disturbance intensity
- Years after disturbance
- Years after logging
- The method of logging/wood extraction (helicopter, forwarder, winching, mules, etc.)
- Intensity of salvage logging
- Time of the year of logging
- Additional post-disturbance actions (e.g. planting)
- Mean sampling-plot area
- Study quality: clarity in the methods (specified as a percentage), proper handling of confounding effects (yes/no), and randomisation (yes/no).

We will also register the category of ecosystem service to perform complementary analyses separated by ecosystem service type. We will make an effort to obtain all these meta-data for each data point; authors will be contacted to clarify any missing information if necessary.

Risk of bias

The potential for bias between studies will be assessed in complementary ways, as follows. First, geographical and disturbance-related bias (e.g. most studies coming from Europe or North America, which is what we expect) will be assessed by quantifying the studies falling into the different categories of disturbance type, forest type, time since disturbance, and geographical region, and the results will be discussed. Second, bias in quantitative analysis due to more than one data point coming from the same study area will be handled through random effects in mixed effects models. And third, publication bias will be tackled both prior to analysis, through contacting researchers to provide unpublished data, and after analysis, with the trim and fill method [21].

Data synthesis and presentation

The data obtained during the review process will be presented in both narrative and quantitative ways. The narrative part will make use of conceptual diagrams and tables to describe the studies that were found (e.g. the number of studies of salvage logging after each kind of disturbance affecting different ecosystem services).

The quantitative data extracted from empirical studies will be assessed with statistical methods through quantitative meta-analysis. The meta-analysis will be formulated so as to answer the primary and all the secondary questions. The results will be presented in the form of figures and tables and thoroughly explained and discussed in the text.

Authors' contributions

AL and JC conceived the study; all authors contributed to the design of the review; AL wrote the first draft; all authors revised the draft and approved the final manuscript.

Author details

[1] Departamento de Ecología, Facultad de Ciencias, Universidad de Granada, 18071 Granada, Spain. [2] Department of Ecology, Swedish University of Agricultural Sciences (SLU), P.O. Box 7044, 750 07 Uppsala, Sweden. [3] Departamento de Ciencias de la Vida, UD Ecología, Edificio de Ciencias, Universidad de Alcalá, 28805 Alcalá de Henares, Spain.

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Compliance with ethical guidelines

Competing interests

The authors declare that they have no competing interests.

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