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[ENVIRONMENTAL IMPACTS OF FOREST CERTIFICATIONS]

Qualitative Literature Review of Scientific Research on the Environmental Impacts of the Forest Stewardship Council (FSC) Certification Scheme and the Programme for the Endorsement of Forest Certification (PEFC) in the Boreal, Temperate and Tropical Biomes.

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1. Introduction

At the beginning of the 1990s, forest certifications were developed as a non-state market-driven response to the failure of governments to halt forest degradation and deforestation. The two main forest certification schemes are Forest Stewardship Council (FSC) founded in 1993, and the Pan-European Forest Certification (PEFC) established in 1999, and later renamed the Programme for the Endorsement of Forest Certification (Berry et al., 2012). Both FSC and PEFC aim at providing social, economic, and environmental benefits for forest owners and timber companies that choose to be certified. By so doing, forest certifications also contribute to the achievement of the Sustainable Development Goals, namely goal 8 *Decent Work and Economic Growth,* goal 12 *Responsible Consumption and Production*, and goal 15 *Life on Land* (FAO, SFM Toolbox). Nine percent of the global forest area is currently being managed under FSC or PEFC standards (Berry et al., 2012), covering approximately 400 million hectares in total (van Oorschot et al., 2014). Ninety-three percent of these forests are in the temperate and boreal biomes (Berry et al., 2012).

Despite being applied for about 20 years, scientific literature on the environmental impacts of forest certifications is scarce. Significant methodological challenges hinder the production of rigorous and verifiable studies on the long-term, and large-scale effects of forest certifications (Berry et al., 2012). In particular, to measure the environmental impacts of forest certifications is a daunting task for two main reasons. First, in both certified and non-certified areas, a systematic collection of data concerning the impacts of forest management on biodiversity is lacking (Van Kuijk et al., 2009). Second, depending on their geographic location, forests comprise of different plant and animal species, and the type of logging intensity and timing, as well as the extraction method and post-harvest treatments, produce different impacts on those (Ibidem).

Yet various studies that evaluate the environmental impacts of forest certifications do exist, but are often limited by design, or their methodology is not sufficiently rigorous to prove causation (Burivalova, 2017). Moreover, the existing scientific literature concerns different species, it involves different field protocols in different biomes and countries, and, generally, the proper temporal and spatial dimensions for forest ecosystems and forestry are not taken into account (Van Kuijk et al., 2009; Burivalova, 2017). Thus, it is difficult to average the results of multiple studies, and to generalize the effects of forest certifications to a continent, or a sub-region, let alone to the world as a whole (Cerutti in Burivalova, 2017). On the other hand, nobody tried so far, for example through a systemic literature review.

This report aims to fill this knowledge gap by presenting the results of a 'qualitative literature review' (QLR) of existing research, on the direct environmental impacts of FSC and PEFC, in the boreal, temperate, and tropical biomes. In particular, this QLR focuses on the following questions:

- What type of impacts do forest certifications have on forest biodiversity and ecosystem services in the boreal, temperate, and tropical biomes?
- To what extent are these impacts positive, negative, or neutral, and to what degree?

It is critically important to provide trustworthy and transparent information on the impacts of forest certification, since this type of data may inform and influence policy-makers, negotiations, and the allocations of funds to support more sustainable forest management practices (Romero et al., 2017). This report tries to do so by offering step-by-step insights into the procedures and results of the QLR.

2. Methodology

A ‘systematic literature review’ aims to identify, evaluate and integrate relevant findings available in the scientific literature to address a generic research question (Siddaway, 2014; Jones et al., 2008; Borenstein et al., 2011; Waddington et al., 2012). Such reviews systematically follow a number of procedural steps: posing a generic research question, collecting relevant literature, assessing the quality of data, in- and excluding of studies based on quality, relevance and ‘risk of bias’, assessing the effect size of the intervention, synthesising the various findings and generalizing the overall impact. All these steps were also followed in this study. However, it was not possible to perform a ‘quantitative meta-analysis’ – one of the variants of a systematic literature review – given the significantly different methodologies used in the scientific literature available, their different area/sample sizes, different logging intensities studied, and different socio-economic conditions of the countries and regions where the field studies were conducted. Therefore, we applied a ‘qualitative literature review’ (QLR).

To evaluate the environmental impacts of FSC and PEFC, relevant scientific literature was collected in online journal databases, such as Science Direct, Elsevier, Scopus, Google Scholar, and Wageningen University and Research online library. Given the difficulty of finding relevant and specific publications online, search terms were kept broad on purpose: “FSC biodiversity impacts” OR “PEFC biodiversity impacts” OR “Forest certifications impacts on biodiversity” OR “Forest certifications” OR “FSC and PEFC” OR “FSC” OR “PEFC”. Additional studies were identified by scanning the bibliography of main reports on the effects of forest certifications (e.g.Van Kuijk et al., 2009; Karmann et al., 2009) , and by examining the list of scientific publications of the most cited authors in this field (‘literature snowballing’). Informal discussions with experts from academia yielded more scientific papers, some of which were already included in the preliminary list.

As for grey literature, nine Ecosystem Services Certification Documents (ESCDs) by ForCES were added to the selection. ForCES is a new project implemented by FSC in collaboration with several international partners, and supported by the Global Environment Facility (GEF). Its main goal is to preserve essential ecosystem services, such as biodiversity conservation, watershed protection, carbon sequestration, and carbon storage in certified forests (ForCES, FSC.org). These documents were included as grey literature for three main reasons: First, the novelty of the initiative. Being a new project, they could provide some interesting information on what the impacts of FSC on ecosystem services are. Second, the impacts are presented in a technical document with a detailed description of the methodology used to measure the outcomes. Third, every ESCD is evaluated by an independent third-party auditor that evaluates the impact against a given set of indicators, whether to approve the claim or not. This last point is particularly important, since the evaluation by an impartial agent guarantees that there is no bias for or against the results reported in the ESCDs.

The collection of literature was conducted in April 2018, and it produced an initial sample of fifty-five papers. Studies were then selected by giving priority to those that aimed at *directly* measuring the impacts of FSC and/or PEFC on forest biodiversity (both flora and fauna), and that were published from 2013 onwards. All case studies which aimed at assessing environmental impacts of forest certifications indirectly, for example by evaluating phenomena often associated with certification (e.g. reduced impact logging (RIL), retention trees, High Conservation Value Forests) were thus excluded. Papers based on comparing ‘Corrective Action Requests’ (CAR) over time were eliminated as well, since these are not based on on-the-ground measurements, so it is not possible to control whether impacts were actually produced, and if so, of which kind and to what degree. To verify if all the nine Ecosystem Services Certification Documents were approved by a third-party auditor, policy managers of ForCES were contacted via email. Out of nine, only five ESCDs were accepted. However, for the final list of this QLR, two documents written in Spanish had to be removed for linguistic limitations. In total, from the initial sample of fifty-five studies, *thirty-one papers* were finally reviewed. These mostly comprise of academic journal papers, some systemic literature reviews, and some grey literature.

The geographic distribution of these case studies covers the three biomes boreal, temperate, and tropical. Within the boreal one, six studies were carried out in Europe; within the temperate biome, one study was carried out in North America, and three in Europe; and within the tropical biome, twenty-one studies were spread over South-America, Africa, and South-East Asia. While all thirty-one papers concerned FSC, only three also involved PEFC.

2.1 Data analysis

Each paper was reviewed on the unit of analysis, the methodology used, and the results obtained. Studies were subsequently classified according to their biome, area/sample size, methodological design, type of forest management, type of ownership, certification analyzed, category of the indicator examined (i.e., flora, fauna, ecosystem services), indicator (e.g. deforestation, species richness, watershed services), type of impact (positive, neutral, negative), and the degree of impact. These data are highlighted in Appendix A. Additional information was collected on continent, country, other studies on the same case, and details on the impact (short description of the results). These are displayed in Appendix B. Finally, a more general and immediate overview of the categories examined, the indicators, the biomes, and the impacts of FSC and PEFC are shown in Appendix C.

The field study area was defined as *very small* when it covers between 0 ha and 1.000 ha; as *small* when it covers between 1.000 ha and 50.000 ha; as *medium* when it covers between 50.000 ha and 200.000 ha; and it was defined as *large* when it covers between 200.000 ha and 1.000.000 ha. As for the degree of impact, environmental effects of FSC and/or PEFC were translated to an ordinal set of values, ranging from +1 to -1. Studies indicating *very positive* impacts, compared to a control plot, were given a value of +1; studies that did not show any change compared to a control plot were given a value of zero, since the impact was *neutral*; and when studies presented *very negative* impacts, compared to a control plot, they were given a value of -1. To describe different degrees of impact between =1 and -1, a set of in-between values were assigned as well: 0,75; 0,50; 0,25; -0,25; -0,50; and -0,75. The values from + 1 to 0,50 represent the different degrees of positive impact,; all the values around 0 (-0,25 to 0,25) represent the different nuances of neutral, and all the values towards -1 represent the different degrees of negative impact.

For instance: In *Tanzania*, Kalonga et al. (2016) provided evidence that FSC certified community forests have significantly higher tree species richness, diversity and density compared to open access forests, and state forest reserves. Considering that the authors indicate a strong positive correlation – but not causation – between FSC certification and biodiversity conservation, and that other factors than certification also contributed to the outcome, the degree of impact was set at 0,75. In *Honduras*, Kukkonen et al. (2009) measured the floristic composition in tree fall gaps in FSC certified community forests applying RIL, compared to conventionally managed and natural forest areas. Results show that certified forests comprise significantly higher light-benefiting taxa, but the study also reports that the gaps in certified forests do not favour a floristic composition similar to natural forest. Therefore, considering that results are positive, but the impact is moderate, the degree of impact was set at 0,50. In *East Kalimantan (Indonesia)*, FSC certification does generally not reduce carbon emissions from logging activities, compared to non-certified concessions. However, emissions from skidding are more than 50% lower in certified concessions (Griscom et al., 2014). This study was therefore assigned a value of 0,25, since its general effect is neutral, except for one specific activity with a positive impact. In *Mexico*, FSC has no statistically significant impact on the rate of deforestation in forest management units (Blackman et al., 2015). For this study, the degree of impact was set at 0. In *Central Vermont (USA)*, Foster et al., (2008) compared FSC certified harvests of sugar maple, with non-certified harvest and reconstructed pre-harvest conditions. Both certified and non-certified harvests have a negative impact on biomass and tree carbon storage. Biomass is reduced by one-third compared to pre-harvest reconstructed conditions, decreasing the potential economic carbon storage values by 25-30%. Considering that FSC has a negative impact compared to pre-harvest reconstructed stands, but not compared to non-certified stands, the negative impact is considered moderate and therefore set at -0,50.

2.2 Limitations of the review

First of all, advocates of 'systemic literature reviews' generally prefer very focused questions, so 'splitting' instead of 'lumping', in order to create a set of comparable studies (Waddington et al., 2012). Yet, given our questions in the above, that include three biomes - and thus developed and developing countries -, we however follow the strategy of 'lumping things together'. We do so because we are - first of all - interested in the *world-wide* environmental impact of forest certification. Moreover, the number of studies is *limited*, hence further splitting would result in a review with hardly any research available. Yet, ‘lumping’ implies that the variation in studies increases, which is good for exploring a theme, but not so good for the comparability of studies. For example, the ‘comparator’ may differ over studies (e.g. non-certified forests, conventionally-logged forests or pristine forests compared to certified forests), the ownership of forests may differ (e.g. state, community, private), putting different rule systems in place, as well as the political and socio-economic context in the various biomes and countries, implying different enabling and/or constraining conditions for forest certification. As a consequence, we should carefully interpret the results of the review.

Secondly, despite this global perspective, the studies involved are unevenly distributed across the three biomes, with the majority of the studies concentrated in the tropical one. Also, they jointly cover about 1.5% of the world’s certified forests only. Both issues imply that the ‘external validity’ of this review is probably limited. We should thus be careful in extending the aggregated results of this review to the globe as a whole.

Thirdly, despite the availability of quantitative data in various studies, it was not possible to perform a ‘quantitative meta-analysis’, as indicated in the above, given the different designs, methodologies and areas/samples used in the literature and the different logging intensities in the plots and socio-economic and political conditions in the countries. For instance, this review includes six studies that aimed at measuring the impact of FSC on tropical deforestation, but each used different methodologies (e.g. synthetic control method, matched difference-in-differences, panel data regression), only two reported their sample size, and they were conducted in different countries with various economic and political conditions (e.g. Indonesia, Mexico, Peru, Cameroon). Considering these differences, a quantitative meta-analytic aggregation was deemed unfeasible, so that we decided to conduct a ‘qualitative literature review’ (See Siddway, 2014; Jones et al., 2008; Borenstein et al., 2011 for a detailed discussion on meta-analysis). This implied that we could not calculate, compare and aggregate the ‘size effect’ of each study. As an alternative, we applied a qualitative degree of impact, as explained in the above. Such ordinal scores of course lack the precision and comparability of a calculated size effect. Moreover, the (inter)subjectivity of what can be defined as 0,75 rather than 0,50 should be kept in mind when reading the scores below and in the table in Appendix B. Nonetheless, they offer some indication of the degree of impact.

Fourthly, our ordinal scores relate to another problem, which Waddington et al. (2012) coin ‘vote counting’. Below, we will sum the number of studies that show specific scores (e.g. 0,5) on specific indicators (e.g. species richness) in specific categories (e.g. flora) in specific biomes (e.g. Tropics). Such vote counting may be tricky, as studies may tremendously differ in design and thus size (like the many dissimilar countries in the United Nations, who all have one vote in decision-making). However, the various studies in this review, from very small to large, show rather similar means of and variance in scores, so there seems no bias of larger studies always resulting in lower and dissimilar scores and smaller studies always in higher and similar scores (or other ways around). Summing scores is therefore less an issue, because always a combination of smaller and larger studies in each category of our review.

Fifthly, this report only includes studies that focus on the environmental impact of FSC and PEFC, not on the impact of silvicultural treatments *as such* that are often associated with certification, an example being Reduced Impact Logging (RIL). This would have expanded the number of studies tremendously, for which we simply lacked time. However, we acknowledge that their inclusion would have added value to this qualitative literature review. Yet, these silvilcultural treatments are referred to below (like RIL), but *only* for as far as these occur in the context of FSC and PEFC.

Finally, this review and the studies it involves may suffer from a number of biases (Waddington et al., 2012). Considering that this report mostly includes published work, it is acknowledged that a ‘publication bias’ might occur. The tendency of journals to avoid publishing small-N studies and/or studies with negative or nil results, might imply an overestimation of (quantified) positive effects in literature reviews. Such is probably also the case for this review, since table 9 and table 10 below (pp. 15-16) show that nearly 70% of the indicators of forest certification’s environmental impact are scored (very) positively, whereas only two out of 31 studies report negative impacts. On the other hand, the grey literature that *is* included also shows positive results, as do the studies that are based on (very) small areas. Such indicates that this review’s publication bias might be limited. Another likely bias is ‘research bias’, that is: researchers might (consciously or unconsciously) steer results towards the ones they prefer. This is a real danger here, because quite some researchers involved in forest certification studies are engaged scientists who would very much like to see the world moving towards more sustainable trajectories. Proving that certification aiming at sustainable forest management does indeed work, might thus be a ‘natural inclination’. However, we cannot specify or quantify this bias. Our general impression is that researchers of the studies involved did a fairly good job in explaining and applying their designs, procedures and protocols in order to avoid manipulation, although sometimes transparency is not optimal (some studies lack information on study area size, and many more on sample size, for example). Thirdly, ‘self-selection bias’. Certification particularly occurred in forests where results could be achieved rather easily (‘low-hanging fruit’). This implies that the starting point of the area, where certification was implemented, might already have been more biodiverse than the comparators used in the various impact studies. Thus, the positive effect is not so much the merit of certification, but of the prior-certification forest itself. Many researchers address this issue, and try to circumvent it, but not all, so it is probably present below. Again, the degree is difficult to assess, but it is a good thing that all biomes are included below, because ‘low-hanging fruit’ certification is particularly considered an issue of the temperate biome. This may remedy the ‘self-selection bias’ in the review a bit. Last but not least: ‘language bias’. Since this literature review only includes scientific literature and some grey literature written in English, studies in other languages were definitely missed. For pragmatic reasons (not mastering other languages, no budget for hiring translators, and some time constraints), we could not solve this issue.

3. Results

In total, the studies jointly cover about six million hectares of certified forests around the world (approximately 1.5% of certified forests globally). But results are unevenly distributed across the three biomes, with the majority of the studies concentrated in the tropical one (see Figure 1).

Figure 1 Geographic distribution of the case studies analyzed.

Concerning the boreal biome, two studies show little to no impact of forest certification in the category flora, whereas three studies indicate, on average, moderate positive impacts. Only one study, measuring the impacts of FSC and PEFC on both flora and ecosystem services, exhibits mixed results. For ecosystem services, results indicate moderate positive effects by both FSC and PEFC.

Regarding the temperate biome, four studies specifically measure the impacts of FSC certification on flora, fauna, and ecosystem services. Out of four, three are carried out in Portugal. All of these provide evidence of positive impacts in all the categories examined. The fourth study was conducted in central Vermont (USA), and it reports no impacts for the category flora, while for ecosystem services the results are mixed, showing both positive and negative impacts.

Concerning the tropical biome and the category flora, eight out of thirteen studies report evidence of positive impacts, four indicate no impacts, while one study presents mixed results, with both positive and negative effects. All these studies specifically concern FSC certification. Impacts on fauna are mainly positive, with all the seven studies providing evidence of success, by both FSC and PEFC. All of them concern FSC and only one also assesses the impacts of PEFC. On ecosystem services, three studies demonstrate that FSC has positive impacts, one indicates no impacts, and one presents both positive and neutral effects. No study on PEFC was identified in this category.

For a quick-scan overview, see the table in Appendix C (p. 28). A more detailed picture of the results is presented below, with the main trends highlighted. Since indicators to examine the impacts of forest certifications vary across studies and biomes, these are listed at the beginning of each section. In addition, an overview of the degree of environmental impact of FSC and PEFC in each biome is tabled at the end of every subchapter.

3.1 FLORA

Boreal biome

Main indicators:

- Area set-asides;
- Potential functional habitat connectivity;
- Structural habitat connectivity;
- Environmentally important areas;
- Tree and high stumps left in the plot;
- Broad-leaved trees and old forests;
- Quality of FSC-certified mature forests.

Case studies in Sweden show different results concerning the effectiveness of certified-driven voluntary set-asides. Whereas Simonsson et al. (2016) concluded that FSC set-asides represent an added value to formally protected areas in terms of size and structural composition, Nordén et al. (2016) reported a lack of incremental effects of both FSC and PEFC certification on the size of areas set-aside for conservation goals.

According to Elbakidze et al. (2011), Swedish FSC certified set-asides, comprising of over-mature and old forests, are located in fragmented forestland properties, and are highly, functionally connected for ‘virtual’ species only needing a small habitat (1 Ha.) (‘virtual’, because these findings are based on computer modelling). The functionality is however low for species requiring 10 Ha., with the highest connectivity for deciduous-coniferous, and the lowest connectivity for coniferous-deciduous old forests. Both over-mature forests and old forests set-asides are not functional for species requiring more than 100 Ha. Regarding the FSC standard content, the Swedish one is principally focused on stand and tree scales.

Similar results are obtained in Lithuania. Elbakidze et al. (2016) showed that the quality of FSC set-asides is low, because particularly non-forest or low productivity forest habitats are set aside. According to future projections made with the habitat suitability index modelling, FSC certified set-asides will be functionally connected only for virtual species with habitat requirements of 1 Ha. Formally protected areas will provide 40% higher functional connectivity for species needing 100 Ha. or more of old pine forests. Both pine and mixed coniferous forests will be functionally connected for species requiring habitats of 1000 Ha. only due to formally protected areas. Concerning content, Lithuanian FSC standards focus on three different spatial scales: trees in a stand, stands in a landscape, and a landscape in an ecoregion.

In Russia, FSC set-asides are functionally connected for species with habitat requirements from 1 to 100 Ha. Almost 100% of deciduous forests and 80% of spruce and deciduous-coniferous over-mature and old forests are functionally connected for species with habitat requirements of 1 to 10 Ha. The functionality of deciduous forests is high for species with a habitat necessity of 100 Ha., and it is medium for species with habitat needs of 1,000 Ha. Regarding content, FSC standards in Russia comprise all scales of biodiversity conservation, from tree to stand, and from landscape to ecoregion (Elbakidze et al., 2011).

In Sweden, for other indicators than set-asides, such as environmentally important areas conserved during felling, and the number of trees and high stumps left in the plots 5 to 7 years after felling, Nordén et al. (2016) showed that both PEFC and FSC do not have an impact on either the conservation of those areas, and the number of trees and high stumps left in the plot. The study further indicates that there is no difference between the two certification schemes, and both of them coincide with the Swedish Forestry Act. The study suggests that both forest certification standards should be strengthened in order to be effective.

Johansson et al., (2011) compared the biological diversity of small-scale PEFC certified properties, and large-scale FSC certified properties, in Sweden. This research found that both broad-leaved trees and old forests are more abundant in small-scale properties than in large-scale properties. However, higher harvesting and silviculture activities occur in PEFC certified small-scale properties, compared to non-certified plots. Although it combines data from the Swedish National Forest Inventory and the Swedish Database for Forest Owner Analysis, this study fails to establish a cause-and-effect relationship with certification.

Finally, in Estonia, Lõhmus et al. (2010) compared old-growth forests with mature FSC certified commercial stands. Results show that FSC certified stands are not significantly different from old growth forests, regarding tree species diversity, volumes of woody debris < 20 cm diameter, and its decay stage composition. Mature stands have more early-successional trees, and have higher overall density and volume of live trees. However, they lack very large trees, especially late-successional deciduous species. To overcome this problem, the study recommends that indicators established by the Estonian FSC standards should be improved, together with silvicultural techniques.

Temperate biome

Main indicators:

- Oak regeneration and the cover, richness and diversity of Mediterranean shrub lands;
- Live tree Characteristics.

In Europe, Dias et al. (2016) compared conservation areas and non-conservation areas in FSC certified cork oak woodlands in Portugal. Results demonstrate that areas set-aside successfully promote the oak regeneration and shrub richness and diversity, suggesting that conservation areas may halt the tree regeneration crisis that this ecosystem is experiencing.

In North America, Foster et al. (2008) compared FSC certified stands of sugar maple in central Vermont, with non-certified harvests, and reconstructed pre-harvest conditions. According to the results, both the FSC-certified harvests and the non-certified ones have a neutral impact on live tree characteristics, in terms of reduced average tree diameter and relative density of sugar maple.

Tropical biome

Main indicators:

- Deforestation;
- Impacts of RIL in FSC-certified areas on forest cover, disturbance and composition; and on floristic composition;
- Impacts of selective logging on structure, composition and diversity of plant communities;
- Impacts of FSC-certified community forests on forest structure and composition.

FSC concessions in Bolivia experience less forest loss, compared to non-certified concessions, and even compared to some country's national protected areas (Killeen et al. 2007; MHNNKM and FAMNK 2006, in Putz et al., 2010). Similar results on deforestation rates at concession level were found in the Maya Biosphere Reserve in Guatemala (Hughell and Butterfield 2008, in Putz et al., 2010).

Rana et al. (2018) measured the impacts of FSC on deforestation in Gabon, Indonesia, and Brazil at forest management unit (FMU) level for the period 2000 to 2012. The study applied a synthetic control method, which accounts for confounding factors through a rigorous counterfactual-based analysis. Results showed that FSC does not reduce deforestation in Gabon, but that it has a small positive impact in Indonesia, and a statistically significant, but variable, positive impact in Brazil. In Indonesia, Miteva et al. (2015) reported that FSC has reduced deforestation by 5% in certified concessions between 2000-2008, although it has increased perforated areas by 4 km^2, on average.

Palanguisi et al. (2015) analyzed the deforestation rate in FSC-certified concessions in Peru and Cameroon. In Peru, among the 525 FSC concessions in the departments of Madre de Dios, Ucayali and Loreto, FSC produces a reduction of the deforestation rate of 0.07% on average per year, but only in the Madre de Dios department. In Cameroon, in the 114 concessions analyzed, FSC has only a small avoided deforestation impact of 0.02% per year. Moreover, in four of the five regions considered, no statistically significant impact was found. In Mexico, Blackman et al., (2015) reported no statistically significant impact concerning avoided deforestation in FMU's as well.

The application of reduced impact logging (RIL) in FSC certified concessions reduces ground disturbance, and decreases the density of roads and skid trails (Feldpausch et al., 2015, in Burivalova et al., 2017). Moreover, FSC certified areas that apply RIL experience less disturbance in terms of canopy openings, and recover more quickly, compared to conventionally logged ones (Trish et al., 2016). A case study in the FSC certified Iwokrama forest in Guyana showed that RIL, compared to unlogged forests, have either a neutral or a positive impact on the density of seedling recruitment of commercially valuable timber species. Pioneer species densities, considered as an indicator of disturbance, remain scarce, suggesting that RIL does not produce negative impacts. For some species, it may even facilitate their establishment (Rivett et al., 2016). In Gabon, in an FSC concession that applies RIL no visible short-term effects on tree species density occur, and only a small impact on tree composition, compared to a conventionally logged area (Medjibe et al., 2013).

Kukkonen et al. (2009) measured the floristic composition of 52 taxa of trees and shrubs in tree fall gaps of certified, conventionally logged and protected forests in northern Honduras. Certified forests that apply RIL have the highest number of light-benefit taxa, but in terms of floristic similarity, conventionally logged areas are more close to natural forests. This study suggests that past logging management activities may have changed the species composition in certified forests. Therefore, restoration operations should be included in certification requirements, together with landscape-level planning and post-logging recovery operations.

In East Kalimantan, De Iongh et al. (2014) compared plots selectively logged 1, 5 and 10 years following FSC guidelines, with a primary forest in the Berau region. This study included canopy, forest floor vegetation, trees, sapling and seedlings, liana and rattan, non-rattan palms, herbs, epiphytes, and mosses. According to the results, tree densities are higher in the primary forests, than in areas logged 1 and 5 years earlier, however, they are similar to the area logged 10 years previously. Pioneer tree species, such as *Macaranga Hypoleuca*, are more abundant in sites logged 1 year previously, than in sites logged 5 and 10 years before, and absent in the primary forest site. Saplings are higher in the sites selectively logged 10 years before, compared to the primary forest. Sapling diversity is similar in the four sites analyzed. Overall, selective logging in accordance with certification procedures is able to successfully preserve biodiversity.

In Tanzania, FSC-certified community forests have the best forest structure, in terms of number of trees, basal area and volume, compared to open access forests and state forest reserves, both non-FSC certified (Kalonga et al., 2015). Moreover, they have significantly higher trees species richness, diversity and density, confirming that FSC certification has a positive impact on biodiversity conservation (Kalonga et al., 2016).

Overview of the (estimated) Degree of Impact on Flora, for each biome.

BOREAL																		
INDICATORS	FSC									PEFC								
	NEGATIVE			NEUTRAL			POSITIVE			NEGATIVE			NEUTRAL			POSITIVE		
	-1	-0,75	-0,5	-0,25	0	0,25	0,5	0,75	1	-1	-0,75	-0,5	-0,25	0	0,25	0,5	0,75	1
Areas set-aside					1	1	1*	2*						1				
Broad-leaved trees						1											1	
Environmentally important areas					1									1				
Mature stands								1										
Old growth forests						1											1	
Potential functional habitat connectivity						1	1*	1*										
Structural habitat connectivity						1	1*	1*										
Trees and high stumps left in the plots					1									1				

Table 1 The table shows for FSC and PEFC how many studies score a positive, neutral, or negative degree of impact for the respective indicators, in the boreal biome. *Note:* The numbers with the asterisk (*) refers to Elbakidze et al., (2011) which measure the impacts of FSC in both Sweden and Russia for three indicators.

With regard to the boreal biome (see Table 1), FSC has a strong positive impact on *Mature stands* (Lõhmus et al., 2010), and on both *Potential functional habitat connectivity* and *Structural habitat connectivity* (Elbakidze et al.,2011 in Russia). Results are mixed for the indicator *Areas set-aside:* two studies report evidence of strong positive impacts (Simonsson et al.,2016; Elbakidze et al.,2011 in Russia), whereas one case study demonstrates that FSC has no statistically significant impact (Nordén et al., 2016). Neither have significant impacts been reported for environmentally important areas, and trees and high stumps left in the plots (Nordén et al., 2016).

PEFC has a strong positive impact on broad-leaved trees and old forests (Johansson et al., 2011). However, it has no impact on areas set-aside, environmentally important areas, and trees and high stumps left in the plots (Nordén et al., 2016).

TEMPERATE																		
INDICATORS	FSC									PEFC								
	NEGATIVE			NEUTRAL			POSITIVE			NEGATIVE			NEUTRAL			POSITIVE		
	-1	-0,75	-0,5	-0,25	0	0,25	0,5	0,75	1	-1	-0,75	-0,5	-0,25	0	0,25	0,5	0,75	1
Cover, richness and diversity of Mediterranean shrublands								1										
Live tree characteristics					1													

Table 2 The table shows for FSC how many studies score a positive, neutral, or negative degree of impact for the respective indicators, in the temperate biome. No studies on PEFC were identified.

In the temperate biome, FSC has a strong positive impact on *the cover, richness, and diversity of Mediterranean shrublands* (Dias et al., 2016). However, it has no impacts on *live tree characteristics* in North America (Foster et al., 2008).

TROPICAL																		
INDICATORS	FSC									PEFC								
	NEGATIVE			NEUTRAL			POSITIVE			NEGATIVE			NEUTRAL			POSITIVE		
	-1	-0,75	-0,5	-0,25	0	0,25	0,5	0,75	1	-1	-0,75	-0,5	-0,25	0	0,25	0,5	0,75	1
Deforestation					1	1	1	3										
Floristic composition							1											
Forest disturbance			1					2										
Forest structure					1			1										
Seedling recruitment						1												
Structure, composition and diversity of plant communities								1										
Tree species richness, diversity and density								2										

Table 3 The table shows for FSC how many studies score a positive, neutral, or negative degree of impact for the respective indicators, in the tropical biome. No studies on PEFC were identified.

Strong positive impacts have been reported for *Tree species richness, diversity, and density* (Kalonga et al., 2016; Burivalova et al., 2017); and *Structure, composition and diversity of plant communities* (De Iongh et al., 2014) in the Tropics. For the indicator *Deforestation*, results vary, with three case studies providing evidence of strong positive impacts (Miteva et al.,2015; Burivalova et al.,2017; Putz et al., 2010), and one study showing no statistically significant impact (Blackman et al., 2015). For two case studies, results range from weak positive impacts to moderate impacts (respectively: Panlasigui et al., 2015; Rana et al., 2018). Mixed results are obtained for *Forest Structure*, with both strong positive impacts (Kalonga et al., 2015) and neutral impacts (Medjibe et al., 2013). Finally, conflicting results are shown for *Forest Disturbance:* two case studies present strong positive impacts (Trish et al., 2016; Burivalova et al., 2017), whereas one case study provides evidence of some negative impact (Miteva et al., 2015).

3.2 FAUNA

Boreal biome

No studies found.

Temperate biome

Main indicator:

- Species Richness.

Dias et al. (2013) measured the absolute biodiversity value of FSC-certified cork oak savannahs in Portugal, compared to non-certified areas. Results demonstrate that this value in certified areas is not significantly higher than in non-certified ones. However, the relative fauna richness – percentage of species richness in a certain plot compared to species richness in the total area – is considerably higher in certified areas than in non-certified sites.

Tropical biome

> *Main indicators:*
>
> - Bird species;
> - Terrestrial herpetofauna;
> - Mammal richness.

Results of various studies confirm that reduced impact logging (RIL) in FSC-certified stands has a strong positive impact on fauna species richness. However, despite being an important element, other factors are also essential for preserving the different animal species. Strict hunting regulation inside the concession areas, and a relative unfragmented landscape surrounding the certified units complement FSC and PEFC efforts to conserve fauna biodiversity.

In Bolivia, FSC certified concessions that apply RIL succeed in preserving the abundance and diversity of understory birds and terrestrial herpetofauna, compared to areas where intensive treatments take place (Putz et al., 2010). Positive results are also reported in East Kalimantan, where RIL has a positive impact on the distribution of animals, compared to conventional logging. In the FSC-certified areas analysed, a large number of mammal and bird species, especially endangered and vulnerable species included in the IUCN Red List, is successfully conserved (ForCES, 2017). Case studies from Guatemala and Peru confirm that RIL does not have negative impacts on large and medium-sized terrestrial mammals, and in some cases, some species will even benefit from the opening of the forest canopy (Tobler et al., 2018; Mohamed et al., 2013).

However, positive impacts are also due to strict hunting regulations in place inside logging concessions (Tobler et al., 2018). The importance of keeping hunting under control is highlighted in a study conducted by Polisar et al., (2017) in four different states in South America. The study aimed to measure the presence of Jaguar populations and prey species in forested areas, certified by either FSC or PEFC, and applying either RIL or selective logging. Results show that a low presence of felids and prey is not directly caused by the type of logging management, but by hunting. In fact, their presence is highest in certified areas connected to protected areas, where hunting is strictly controlled. Similar results are obtained from the Republic of Congo, where large quantities of forest buffalo and elephants are found in FSC certified logging concessions, close to protected areas with hunting restrictions (Clark et al., 2009 in Putz et al., 2010).

In South-East Asia, studies conducted in the FSC-certified Deramakot Forest Reserve confirm that reduced impact logging does not negatively affect mammal biodiversity, including the Endangered Bornean Orangutan (*Pongo Pygmaeus*, Linnaeus, 1760), and the critically Endangered Sunda Pangolin (*Manis javanica*, Desmarest, 1822) (Payne et al., 2008 in Putz et al., 2010; Sollmann et al., 2017). Moreover, the Deramakot Forest Reserve has a higher presence of some of the large mammals, compared to the surrounding protected areas, due to strict hunting controls inside the area (Mannan et al., 2008 in Putz et al., 2010).

Overview of the (estimated) Degree of Impact on Fauna, for each biome.

TEMPERATE																		
INDICATORS	FSC									PEFC								
	NEGATIVE			NEUTRAL			POSITIVE			NEGATIVE			NEUTRAL			POSITIVE		
	-1	-0,75	-0,5	-0,25	0	0,25	0,5	0,75	1	-1	-0,75	-0,5	-0,25	0	0,25	0,5	0,75	1
Species richness								1										

Table 4 The table shows for FSC how many studies score a positive, neutral, or negative degree of impact for the respective indicators, in the temperate biome. No studies on PEFC were identified.

Only one study has been found for this biome regarding the impact of FSC on *Species richness*. Results show strong positive effects (Dias et al., 2013).

TROPICAL																		
INDICATORS	FSC									PEFC								
	NEGATIVE			NEUTRAL			POSITIVE			NEGATIVE			NEUTRAL			POSITIVE		
	-1	-0,75	-0,5	-0,25	0	0,25	0,5	0,75	1	-1	-0,75	-0,5	-0,25	0	0,25	0,5	0,75	1
Bird species								2										
Mammal richness							2	3								1		
Species richness								3										

Table 5 The table shows for FSC and PEFC how many studies score a positive, neutral, or negative degree of impact for the respective indicators, in the tropical biome.

FSC has strong positive impacts for the three indicators examined. In particular, on *Species richness* (Putz et al., 2010; Burivalova et al., 2017; Sollmann et al., 2017), and *Bird species* (Putz et al., 2010; ForCES, 2017) FSC has unequivocal strong positive effects. On *Mammal richness* strong positive impacts are reported in three case studies (Putz et al., 2010; ForCES, 2017; Tobler et al., 2018), whereas according to two case studies, FSC produces moderate positive impacts (Polisar et al., 2017; Mohamed et al., 2013). PEFC shows moderate positive impacts for *Mammal richness* (Polisar et al., 2017).

3.3 ECOSYSTEM SERVICES

Boreal biome

Main indicator:

- Dead Wood.

In Sweden, Johansson et al. (2011) discovered that both PEFC and FSC certification foster the volume of dead wood in both small-scale private land and in large-scale forestland owned by different companies. However, the increase is only statistically significant in two regions out of four.

Temperate biome

Main indicators:

- Ecological Condition of Mediterranean streams;
- Biomass;
- Tree Carbon Storage;
- Coarse woody debris.

In Portugal, Dias et al. (2015) analysed the ecological condition of Mediterranean streams in areas with 3 and 5 years of FSC certification, compared to non-certified areas and to least disturbed streams. Results demonstrate that FSC has a positive impact on the examined streams, however, these effects are measurable only after 5 years, when the plots become more similar to least disturbed streams. Indeed, the riparian vegetation of streams in areas with 5 years of certification is more dense, constant, and diverse, compared to those in non-certified areas, or areas with 3 years of certification.

In North America, FSC-certified and uncertified stands of sugar maple are one-third smaller in terms of biomass than (reconstructed) pre-harvest stands. This reduction of biomass decreased the potential economic carbon storage value by 25-30%. However, total coarse woody debris volumes, both standing and downed, are significantly higher in certified stands than in non-certified ones (Foster et al., 2008).

Tropical biome

Main indicators:

- Carbon emissions and storage;
- Air pollution;
- Fire incidence;
- Watershed services.

In terms of carbon storage, RIL applied under FSC certification succeeds in maintaining the carbon stock stable, although fluctuations occur between the frequency of high-stock forests and moderate stock forests in East Kalimantan. (ForCES, 2017). Griscom et al. (2014) measured the carbon emissions performance of commercial logging in East Kalimantan. The study found that RIL applied in FSC-certified concessions do not produce lower carbon emissions from logging activity. However, emissions from skidding are more than 50% lower in certified concessions, compared to non-certified ones.

In Indonesia, according to Miteva et al. (2015), FSC-certified concessions have experienced a reduction in air pollution by 31% on average, between 2000 and 2008.

Concerning fire incidences, results are mixed. While in Indonesia FSC concessions do not show a statistically significant reduction in fire incidence (Miteva et al., 2015), FSC certified community forests face less fire incidence in Tanzania, compared to open access forests and state forests reserves, both non-certified (Kalonga et al., 2015).

FSC is reported to have a positive impact on watershed services in a community forest in Indonesia, which applies small and low-intensity management (SLIMF). Results indicate that SLIMF has produced an increase in low vegetation (grass, soil and open land) and middle vegetation (low-density forests and shrub) (ForCES, 2016).

Overview of the (estimated) Degree of Impact on Ecosystem Services, for each biome.

	BOREAL																	
INDICATORS	FSC									PEFC								
	NEGATIVE			NEUTRAL			POSITIVE			NEGATIVE			NEUTRAL			POSITIVE		
	-1	-0,75	-0,5	-0,25	0	0,25	0,5	0,75	1	-1	-0,75	-0,5	-0,25	0	0,25	0,5	0,75	1
Dead wood							1									1		

Table 6 The table shows for FSC and PEFC how many studies score a positive, neutral, or negative degree of impact for the respective indicators, in the boreal biome.

A case study in Sweden reports that both FSC and PEFC have a moderate positive impact on the volume of *Dead wood* (Johansson et al., 2011).

TEMPERATE																		
INDICATORS	FSC									PEFC								
	NEGATIVE			NEUTRAL			POSITIVE			NEGATIVE			NEUTRAL			POSITIVE		
	-1	-0,75	-0,5	-0,25	0	0,25	0,5	0,75	1	-1	-0,75	-0,5	-0,25	0	0,25	0,5	0,75	1
Biomass			1															
Coarse Woody Debris Volumes								1										
Ecological condition of Mediterranean streams							1											

Table 7 The table shows for FSC how many studies score a positive, neutral, or negative degree of impact for the respective indicators, in the temperate biome. No studies on PEFC were identified.

FSC exhibits a strong positive impact on *Coarse woody debris volumes* (Foster et al., 2008), a moderate positive impact on the *Ecological condition of Mediterranean streams* (Dias et al., 2015), and a moderate negative impact on *Biomass* (Foster et al., 2008).

TROPICAL																		
INDICATORS	FSC									PEFC								
	NEGATIVE			NEUTRAL			POSITIVE			NEGATIVE			NEUTRAL			POSITIVE		
	-1	-0,75	-0,5	-0,25	0	0,25	0,5	0,75	1	-1	-0,75	-0,5	-0,25	0	0,25	0,5	0,75	1
Air pollution								1										
Carbon emissions						1												
Carbon storage							1											
Fire incidence					1			1										
Watershed services							1											

Table 8 The table shows for FSC how many studies score a positive, neutral, or negative degree of impact for the respective indicators, in the tropical biome. No studies on PEFC were identified.

FSC has strong positive impacts on *Air pollution* (Miteva et al., 2015). Concerning *Fire incidence* results are mixed: one case study reports evidence of positive impacts (Kalonga et al., 2015), whereas according to another case study (Miteva et al., 2015) FSC has no impact on the occurrence of fire. Moderate positive impacts are demonstrated for *Carbon storage* (ForCES, 2017) and *Watershed services* (ForCES, 2016). Finally, only a weak positive impact has been identified for *Carbon emissions* (Griscom et al., 2014).

4. Conclusions

In total, the 31 studies reviewed cover about 6 million hectares of certified forests around the world (approximately 1.5% of certified forests globally). Impacts of forest certifications were evaluated across the three main biomes (boreal, temperate, tropical), and according to three categories (flora, fauna, ecosystem services). Based on the results obtained, it is not possible to draw aggregated, generalizable and exhaustive conclusions about the environmental impacts of forest certifications world-wide, due to a number of limitations (scattered literature, different impact assessment methodologies, exclusion of most grey literature, risk of biases, amongst others). However, some general patterns can be extracted.

Overall, FSC and PEFC certifications produce positive environmental impacts, compared to non-certified, conventionally logged forests. Strong positive impacts are in particular reported for fauna, where all studies included demonstrate that both FSC and PEFC succeed in preserving animal species, including ones listed as endangered and vulnerable by IUCN. However, these positive outcomes are only achieved if logging intensity is low, if certified forests are surrounded by a relatively un-fragmented landscape, and if hunting is strictly controlled. Such highlights the crucial importance of contextual, enabling conditions for certification systems to produce positive results. Generally, impacts on flora and ecosystem services are also positive, but moderately so.

One should acknowledge that these categories (flora, fauna, ecosystem services) might exhibit trade-offs, and will therefore never score max positively on all indicators. What is good for certain fauna (open forests) is not necessarily good for all flora (dense diverse forests); and what is good for ecosystem services (max biomass for carbon sequestration) is not necessarily good for other flora (forests gaps with a diversity of plants).

For the boreal biome, studies indicate three main issues, Firstly, FSC-certified set-asides are functionally highly connected for species with small habitats requirements only (1 Ha.), so connectivity is not provided for species who demand bigger territories. Secondly, it is unclear whether certified set-asides, both FSC and PEFC, are an added value to ‘normal’ conservation measures, or not. Thirdly, several studies call for a strengthening and harmonization of national FSC indicators related to biodiversity conservation, in order to be more effective on the ground.

For the temperate biome, studies in Portugal have shown the importance of FSC-certified forests to protect and enhance landscapes important to biodiversity, such as cork oak savannahs. Positive results were consistently reported in the three categories flora, fauna, and ecosystem services.

For the tropical biome, FSC succeeds in halting or reducing deforestation in most reported cases, with positive results obtained in comparison to both conventionally logged forests and protected areas. However, in one reported case, FSC increased the perforation of forests, and in another one, FSC did not have any statistically significant impact.

The application of RIL in certified plots stands out as being particularly beneficial. Studies that analyse its effects mostly show positive impacts on both flora and ecosystem services.

Table 9 and Table 10 below summarize the overall degree of impact of FSC and PEFC in the three main biomes, respectively.

FSC										
BIOME	**CATEGORIES**	**DEGREE OF IMPACT (Estimated)**								
		Negative			Neutral			Positive		
		-1	-0,75	-0,5	-0,25	0	0,25	0,5	0,75	1
Boreal	FLORA					3	5	3*	5*	
	FAUNA									
	ECOSYSTEM SERVICES							1		
Temperate	FLORA					1			1	
	FAUNA								1	
	ECOSYSTEM SERVICES			1				1	1	
Tropical	FLORA			1		2	2	2	9	
	FAUNA							2	8	
	ECOSYSTEM SERVICES					1	1	2	2	

Table 9 This table shows the overall scores of FSC for the indicators analyzed in each category (Flora, Fauna, and Ecosystem Services), in the three biomes. *Note:* The numbers with the asterisk (*) refers (also) to Elbakidze et al., (2011) which measured the impacts of FSC in both Sweden and Russia. Results in Sweden scored a 0,50 for three indicators, whereas in Russia, for the same indicators, results scored 0.75.

For FSC, thirty-eight out of fifty-five scores show clear positive impacts on the three categories analysed, and across the three biomes. Fifteen scores indicate little to no impact, and only two scores indicate (moderate) negative effects. Yet these two negative impacts result from a comparison with *non*-logged, relatively *un*disturbed forests, so compared to non-certified, conventionally-logged forests, these impacts could still be *positive*.

Concerning the environmental impacts of PEFC, four out of seven scores indicate positive effects on flora, fauna and ecosystem services; and three scores indicate no statistically significant impact (see table 10 below).

PEFC										
BIOME	**CATEGORIES**	**DEGREE OF IMPACT (Estimated)**								
		Negative			Neutral			Positive		
		-1	-0,75	-0,5	-0,25	0	0,25	0,5	0,75	1
Boreal	FLORA					3			2	
	FAUNA									
	ECOSYSTEM SERVICES							1		
Temperate	FLORA									
	FAUNA									
	ECOSYSTEM SERVICES									
Tropical	FLORA									
	FAUNA							1		
	ECOSYSTEM SERVICES									

Table 10 This table shows the overall scores of PEFC for the indicators analyzed in each category (Flora, Fauna, and Ecosystem Services), in the three biomes.

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APPENDIX A - Overview of studies on the direct impacts of forest certifications.
The data presented in this table concern only the certified areas analyzed.

Author	Biome	Area size	Type of Forest Management	Type of Ownership	Type of forest certification	Category	Indicator	Study Design
1. Blackman et al., 2015	Tropical	Small	_	CFM	FSC	Flora	Deforestation	Comparative case study, with controls selected rigorously, and some confounding factors taken into account.
2. Burivalova et al.,2017	Tropical	_	RIL	Industrial private ownership, CFM	FSC	Flora	Deforestation Forest Disturbance Tree species richness, diversityand density	Systematic Review
						Fauna	Species richness	
3. De Iongh et al., 2014	Tropical	Very small	Selective Logging	State property	FSC	Flora	Structure, composition and diversity of plant communities	Comparative case study
4. Dias et al., 2013	Temperate	Medium	_	_	FSC	Fauna	Birds, Reptiles, Amphibians	Comparative case study
5. Dias et al., 2015	Temperate	Medium	_	_	FSC	Ecosystem Services	Ecological Condition of Mediterranean streams	Comparative case study
6. Dias et al., 2016	Temperate	Very small	_	_	FSC	Flora	Oak regeneration and the cover, richness and diversity of Mediterranean shrublands	Simple case study

Area Size	
[0, 1,000] ha	Very small scale
[1,000, 50,000] ha	Small scale
[50,000, 200,000] ha	Medium scale
[200,000, 1,000,000] ha	Large scale

Author	Biome	Area size	Type of Forest Management	Type of Ownership	Type of forest certification	Category	Indicator	Study Design
7. ESCD, Indonesia, 2017	Tropical	Medium	RIL	Industrial Private ownership	FSC	Ecosystem Services	Carbon Storage	Simple case study
8. ESCD, Indonesia, 2017	Tropical	Medium	RIL	Industrial Private ownership	FSC	Fauna	Terrestrial mammal Bird species	Simple case study
9. ESCD, Indonesia, 2016	Tropical	Very small	Small and low intensity managed forest (SLIMF)	CFM	FSC	Ecosystem Services	Watershed Services	Simple case study
10. Elbakidze et al., 2011	Boreal	*In Sweden:* Large *In Russia:* Large	SFM	*In Sweden:* Different ownership type *In Russia* : State property.	FSC	Flora	Areas set-aside Potential Functional Habitat Connectivity Structural Habitat Connectivity	Comparative case study
11. Elbakidze et al., 2016	Boreal	Large	_	State property	FSC	Flora	Areas set-aside Potential Functional Habitat Connectivity Structural Habitat Connectivity	Comparative case study
12. Foster et al., 2008	Temperate	_	Partial harvest treatment	Non-industrial private ownership	FSC	Flora	Live tree Characteristics	Comparative case study, with controls selected rigorously
						Ecosystem Services	Coarse Woody Debris Biomass	

Area Size	
[0, 1,000] ha	Very small scale
[1,000, 50,000] ha	Small scale
[50,000, 200,000] ha	Medium scale
[200,000, 1,000,000] ha	Large scale

Author	Biome	Area size	Type of Forest Management	Type of Ownership	Type of forest certification	Category	Indicator	Study Design
13. Griscom et al., 2014	Tropical	_	RIL	_	FSC	Ecosystem Services	Carbon Emissions	Comparative case study
14. Johansson et al., 2011	Boreal	_	_	Non-Industrial private ownership; Industrial private ownership; State property	FSC - PEFC	Flora	Broad-leaved Trees; Old Forests	Comparative case study
						Ecosystem Services	Dead Wood	
15. Kalonga et al., 2015	Tropical	Small	_	CFM	FSC	Flora	Forest Structure	Comparative case study, with some confounding factors taken into account.
						Ecosystem Services	Fire Incidence	
16. Kalonga et al., 2016	Tropical	Small	SFM	CFM	FSC	Flora	Tree species richness, diversity and density	Comparative case study, with controls selected rigorously, and some confounding factors taken into account.
17. Kukkonen et al., 2009	Tropical	Very small	RIL	CFM; State property.	FSC	Flora	Floristic Composition	Comparative case study
18. Lõhmus et al., 2010	Boreal	-	Clear cutting, retention cutting	State property	FSC	Flora	Mature Stands	Comparative case study

Area Size	
[0, 1,000] ha	Very small scale
[1,000, 50,000] ha	Small scale
[50,000, 200,000] ha	Medium scale
[200,000, 1,000,000] ha	Large scale

Author	Biome	Area size	Type of Forest Management	Type of Ownership	Type of forest certification	Category	Indicator	Study Design
19. Medjibe et al., 2013	Tropical	Very small	RIL	Industrial private ownership	FSC	Flora	Forest Structure	Comparative case study, with some confounding factors taken into account.
20. Miteva et al., 2015	Tropical	_	RIL	Industrial and Non-Industrial private ownership	FSC	Flora	Deforestation Forest Disturbance	Comparative case study, with controls selected rigorously
						Ecosystem Services	Fire Incidence Air Pollution	
21. Mohamed et al., 2013	Tropical	Medium	RIL, No logging activity	State property	FSC	Fauna	Mammal richness	Comparative case study
22. Nordén et al., 2016	Boreal	_	_	Non-Industrial private ownership	FSC - PEFC	Flora	Areas set-aside Environmentally Important Areas Tree and high stumps left in the plots	Comparative case study
23. Panlasigui et al., 2015	Tropical	_	_	_	FSC	Flora	Deforestation	Simple case study with some confounding factors taken into account
24. Polisar et al, 2017	Tropical	Medium	Selective Logging, RIL	Industrial private ownership, State property, CFM	FSC - PEFC	Fauna	Mammal Richness	Comparative case study

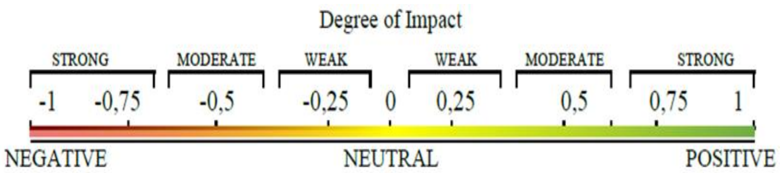
Area Size	
[0, 1,000] ha	Very small scale
[1,000, 50,000] ha	Small scale
[50,000, 200,000] ha	Medium scale
[200,000, 1,000,000] ha	Large scale

Author	Biome	Area size	Type of Forest Management	Type of Ownership	Type of forest certification	Category	Indicator	Study Design
25. Putz et al., 2010	Tropical	_	_	_	FSC	Flora	Deforestation	Literature review
						Fauna	Bird Species Mammal Richness Species Richness	
26. Rana et al., 2018	Tropical	*In Brazil:* large ; *In Gabon:* large ; *In Indonesia:* medium	_	Industrial private ownership	FSC	Flora	Deforestation	Simple case study, with some confounding factors taken into account
27. Rivett et al., 2016	Tropical	Large	RIL	State property	FSC	Flora	Seedling Recruitment	Comparative case study
28. Simonsson et al., 2016	Boreal	Large	_	Industrial private ownership	FSC	Flora	Areas set-aside	Comparative case study
29. Sollmann et al., 2017	Tropical	Medium	RIL	State property	FSC	Fauna	Species Richness	Comparative case study
30. Tobler et al., 2018	Tropical	_	RIL	Industrial private ownership	FSC	Fauna	Mammal Richness	Simple case study
31. Tritsh et al., 2016	Tropical	Small	RIL	Industrial private ownership	FSC	Flora	Forest Disturbance	Comparative case study

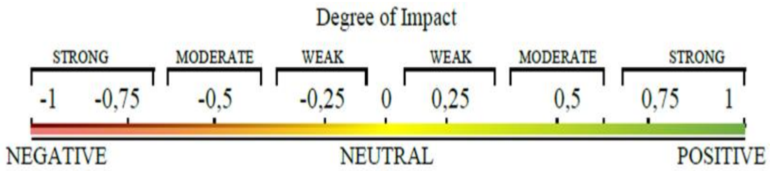
Area Size	
[0, 1,000] ha	Very small scale
[1,000, 50,000] ha	Small scale
[50,000, 200,000] ha	Medium scale
[200,000, 1,000,000] ha	Large scale

Appendix B - Database of studies with details of the impacts.

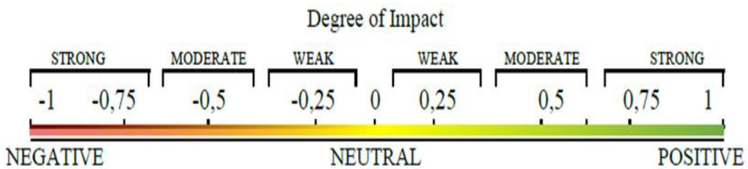
Author	Indicators	Type of impact			Degree of Impact (Estimated)	Notes	Biome	Continent	Country
		Positive	Neutral	Negative					
1 Blackman et al., 2015	Deforestation		FSC		0	A comparison between FSC-certified with uncertified FMUs in Mexico showed no evidence that FSC stems deforestation. The study used FMU-level 2001-2012 panet data set (including information on forest loss, certification, regulatory permitting, geophysical and socioeconomic land characteristics), together with difference-in-difference models and matching. .	Tropical	America	Mexico
2 Burivalova et al., 2017	Deforestation	FSC			0,75	This systematic review compares, inter alia, certified or RIL-based industrial forest management versus conventional industrial forest management. Results showed that certified forests suffered less deforestation than conventionally logged forests; RIL resulted in less ground disturbance and a lower density of roads and skid trails; Areas subjected to RIL had more plant and animal species, and had a higher abundance of animals, even after accounting for logging intensity.	Tropical	Several	Several
	Forest Disturbance	FSC			0,75				
	Tree species richness, diversity, and density.	FSC			0,75				
	Species richness	FSC			0,75				



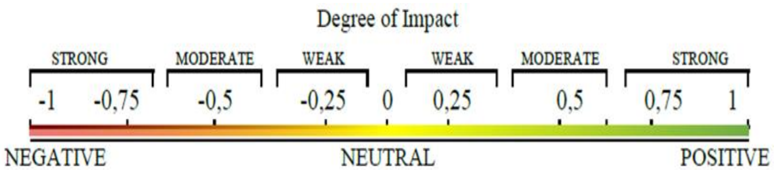
3 De Iongh et al., 2014	Structure, composition and diversity of plant communities	FSC			0,75	The study compared three forest sites logged selectively 1,5, and 10 years previously (following certified procedures) with a primary forest in East Kalimantan. Results demonstrated that forests logged under certified regimes still had high plant diversity, suggesting that biodiversity values could be preserved by following certification procedures.	Tropical	South-East Asia	Indonesia
4 Dias et al., 2013	Birds, Reptiles, Amphibians	FSC			0,75	The study compared the biodiversity values of FSC certified and non-certified areas in cork oak savannas, for birds, reptiles, and amphibians. The relative richness of certified areas included 81% of all birds, 72% of all reptiles, 80% amphibians, and 65% of the threatened species.	Temperate	Europe	Portugal
5 Dias et al., 2015	Ecological Condition of Mediterranean Streams	FSC			0,50	The study compared the ecological condition of streams located in areas with 3 and 5 years of FSC certification; with streams located in non-certified areas, and least disturbed streams. Positive effects were measurable only after 5 years of certification.	Temperate	Europe	Portugal



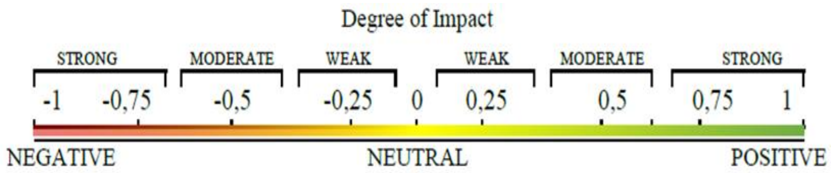
6 Dias et al., 2016	Oak regeneration and the cover, richness and diversity of Mediterranean shrublands	FSC			0,75	In conservation zones, oak regeneration was more abundant, and species richness, and diversity of shrubs were significantly higher, than non conservation zones in FSC certified cork oak woodlands. Higher abundance of seedlings and saplings in conservation zones could be due to low or no livestock grazing and less frequent shrub clearing. under forest certification.	Temperate	Europe	Portugal
7 ESCD, Indonesia, 2017	Carbon Storage	FSC			0,50	This document analyzed the impact of FSC on carbon sequestration and storage, within the certified area. Results the total carbon stock within the FMU was stable, reflecting sustainable yield of logs and fostered regeneration.	Tropical	South-East Asia	Indonesia
8 ESCD, Indonesia, 2017	Terrestrial mammal and Bird species	FSC			0,75	This document presented the impacts of FSC on biodiversity, within the certified area. Results showed that none of the endangered and vulnerable species identified were decreasing.	Tropical	South-East Asia	Indonesia
9 ESCD, Indonesia, 2016	Watershed services	FSC			0,50	This document showed the impacts of FSC on watershed services, within the certified area. Results indicated an increase in low vegetation (grass, soil, and open land) and middle vegetation (forest low intensity, such as shrubs).	Tropical	South-East Asia	Indonesia



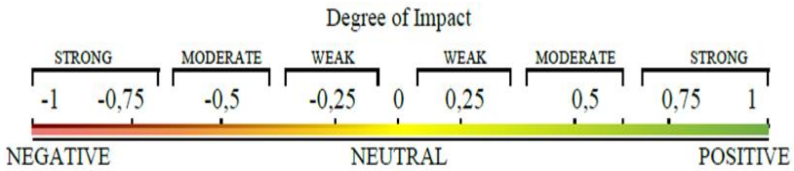
					Sweden	Russia				
10 Elbakidze et al., 2011	Areas set-aside	FSC			0,50	0,75	The study compared the areas of formally and voluntarily set aside forests for biodiversity conservation in Sweden and Russia. The study also measured the structural habitat connectivity of FSC certified set asides by using morphological spatial pattern analysis, and their potential functional habitat connectivity, by applying habitat suitability index modelling for virtual species . According to the authors, strong positive results were obtained in Russia since forest managers received a long term education concerning biodiversity issues. Moreover, forest managers cooperate on a regional and national scale with research organizations in order to identify and map pristine forests and HCVFs. Finally, in Russia remnants of naturally dynamic forests are more abundant than in Sweden.	Boreal	Europe	Sweden and Russia
	Potential Functional Habitat Connectivity	FSC			0,50	0,75	In both Sweden and Russia, over-mature and old forests were highly functionally connected for virtual species with small habitat requirements (1ha).			
	Structural Habitat Connectivity	FSC			0,50	0,75	In Russia the functional connectivity was generally high for species with habitat requirements of 100 and 1000 ha.			



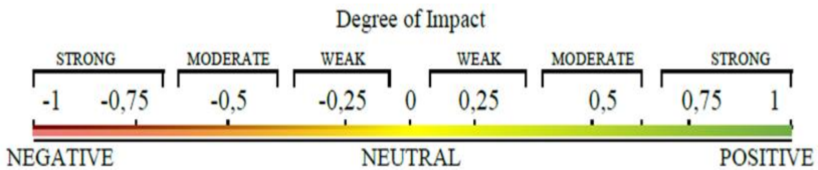
11 Elbakidze et al., 2016	Areas set-aside		FSC		0,25	By using the morphological spatial pattern analysis, and habitat suitability modelling, the study investigated the structural and functional habitat connectivity of formally and voluntarily set-asides for biodiversity consevation. Results showed that the quality of FSC certified set asides was low, since non-forest or low productivity forest habitats are set aside.	Hemi-boreal	Europe	Lithuania
	Potential Functional Habitat Connectivity		FSC		0,25				
	Structural Habitat Connectivity		FSC		0,25				
12 Foster at al., 2008	Live Tree Characteristics		FSC		0	The study analyzed the forest structure on three FSC-certified stands, three uncertified stands, and six adjacent unharvested reference stands, comprising mainly *Acer saccharum*. All harvests lowered potential economic carbon storage values by 25-30%, compared to pre-harvest reconstructed conditions.	Temperate	America	United States
	Coarse Woody Debris	FSC			0,75				
	Biomass			FSC	-0,50				
13 Griscom et al. 2014	Carbon Emissions		FSC		0,25	FSC certified concessions compared with noncertified concessions did not have lower carbon emissions from logging activities. However, emissions from skidding were more than 50% lower in certified concessions. This positive result was achieved through improved planning of bulldozer skid trails to decrease their overall lenght and operation of bulldozers, in order to reduce their impacts per unit lenght.	Tropical	South East Asia	Indonesia



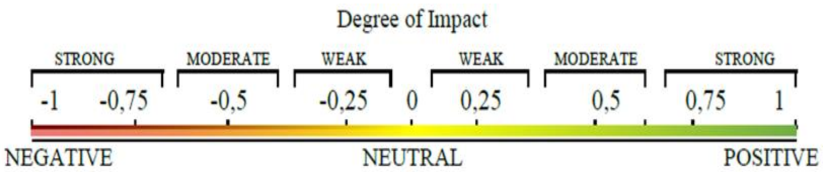
14 Johansson et al., 2011					PEFC	FSC	The study compared the biological diversity (in terms of dead wood, broad-leaved trees, and old forests) of small-scale PEFC certified properties with large-scale FSC certified properties. Results showed that improvements were more evident for small-scale private properties (PEFC), than for the large scale ones (FSC).	Boreal	Europe	Sweden
	Dead Wood	FSC-PEFC			0,50	0,50				
	Broad-leaved Trees	PEFC	FSC		0,75	0,25				
	Old Forests	PEFC	FSC		0,75	0,25				
15 Kalonga et al., 2015	Forest Structure	FSC			0,75		This is a comparative study of FSC-certified community forests, open access forests (non-FSC) and state forest reserves (non-FSC) in Kilwa District, Tanzania. Results showed that community forests FSC certified had a better forest structure, better regeneration, and lower fire incidences than open access and state forest reserves. Possible factors explaining the positive results are harvesting levels and fire incidences, distance from forests to forest products utilisation centres, and forest governance and institutions.	Tropical	Africa	Tanzania
	Fire Incidence	FSC			0,75					
16 Kalonga et al., 2016	Tree species richness, diversity and density	FSC			0,75		This study compared FSC-certified community forests, with open access forests (non-FSC) and state forest reserves (non-FSC) in Kilwa District, Tanzania. Results showed that there were significantly higher tree species richness, diversity, and density in certified community forests, than open access and state forest reserves.	Tropical	Africa	Tanzania



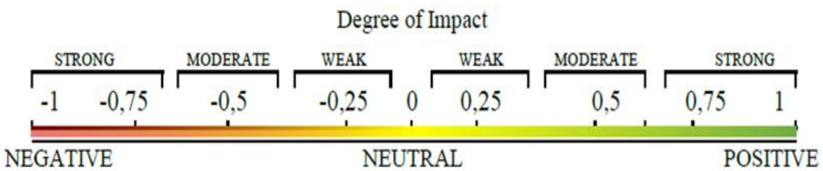
17 Kukkonen et al., 2009	Floristic Composition	FSC			0,50	The study compared the floristic composition of 52 taxa of trees and shrubs in treefall gaps of certified, conventionally managed and protected forests in northern Honduras. The highest abundance of light-benefiting taxa was found in certified forests, whereas conventionally managed forests were floristically more similar to natural forests. The environmental conditions measured in certified gaps were not favourable for a natural forest floristic composition.	Tropical	Central America	Honduras
18 Lõhmus et al., 2010	Mature Stands	FSC			0,75	The study compared four types of old-growth forests (dry boreal forests; Meso-eutrophic forests; Eutropic boreo-nemoral forests;and Mobile-water swamp forests of > 120 years old) with mature commercial stands FSC certified (60-100 years old). Results demonstrated that mature stands did not differ significantly from old-growth forests, in terms of tree-species diversity, volumes of woody debris of < 20 cm diameter, and its decay-stage composition.	Boreal	Europe	Estonia
19 Medjibe et al., 2013	Forest Structure		FSC		0	The study compared a FSC certified forest concession with an adjacent uncertified conventionally logged forest concession in Gabon. Results showed that selective timber harvesting had no apparent short-term effects on tree species density, and little impact on composition.	Tropical	Africa	Gabon



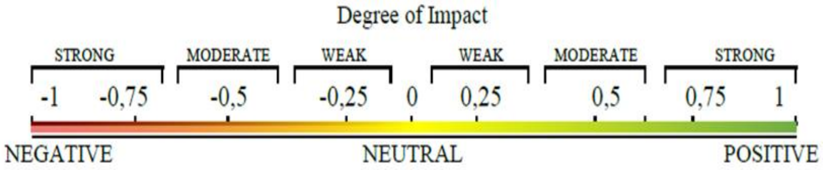
20 Miteva et al., 2015	Deforestation	FSC			0,75	This study used temporally and spatially explicit village-level data on environmental and socio-economic indicators in Kalimantan, to evaluate the performance of the FSC-certified timber concessions, compared to non-certified logging concessions. By using triple difference matching estimators, results showed that FSC reduced deforestation by 5% in certified villages, but it also increased perforated areas. The study did not find any statistically significant impact on fires incidence, but FSC reduced air pollution by 31%.	Tropical	South-East Asia	Indonesia
	Forest Disturbance			FSC	-0,50				
	Fire Incidence		FSC		0				
	Air Pollution	FSC			0,75				
21 Mohamed et al., 2013	Mammal richness, namely Leopard cat (Prionalurus bengalensis)	FSC			0,50	The study compared three commercially used forests: the Deramakot Forest Reserve (FSC certified since 1997), the Segaliud Lokan Forest Reserve (certified by the Malaysian Timber Certification Scheme in 2009), and the Tangkulap-Pinangah Forest Reserve (FSC certified since 2011). According to the results the Leopard cat seemed to benefit from the opening of forests. It is an exception among tropical rainforest carnivores.	Tropical	South-East Asia	Sabah, Malaysia Borneo



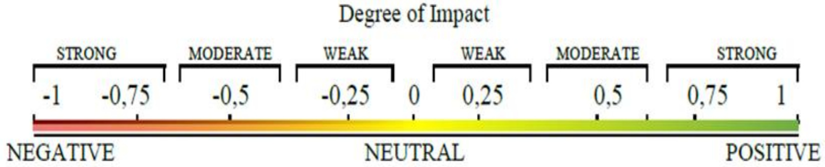
					PEFC	FSC				
22 Nordén et al., 2016	Areas set-aside Environmentally Important Areas Tree and high stumps left in the plot		FSC-PEFC FSC-PEFC FSC-PEFC		0 0 0	0 0 0	The study used detailed forest inventory data of nonindustrial private forest owners at the plot level, both before and after the felling, to measure the effects of FSC and PEFC on avoided degradation, compared to non-certified plots. The study found that both certifications have not halted forest degradation, and that there is no difference between the two certifications, and the Swedish Forestry Act.	Boreal	Europe	Sweden
23 Panlasigui et al., 2015	Deforestation		FSC		0,25		The study investigated the yearly deforestation rates, for the time period 2000-2013, inside 525 FSC certified logging concessions in Peru, and inside 114 concessions in Cameroon. Only one region, in Peru, had an average reduction of 0.07%, per year. In Cameroon, there was a small average deforestation impact of 0.02% per year	Tropical	South America and Africa	Peru and Cameroon
					PEFC	FSC				
24 Polisar et al., 2017	Mammal Richness, namely Jaguars (*Panthera onca*)	FSC-PEFC			0,50	0,50	The study presented the data obtained through jaguar camera trap surveys conducted in forest areas of French Guiana, Guatemala, Bolivia, and Nicaragua. Results indicated that the type of logging is essential in preserving Jaguar populations; however, hunting and the landscape context are important factors that need to be taken into account.	Tropical	South America	French Guiana; Bolivia; Nicaragua and Guatemala



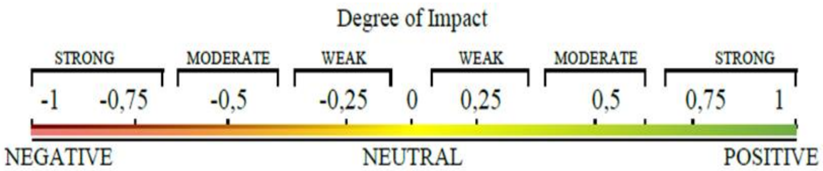
25 Putz et al., 2010	Bird Species	FSC			0,75		Tropical	South America	Bolivia
	Mammal Species	FSC			0,75	FSC did not have negative impacts on the abundance and composition of understorey birds, terrestrial amphibians or terrestrial reptiles.			
	Species Richness	FSC			0,75				
	Deforestation	FSC			0,75	FSC concessions experinced less deforestation compared to both non-certified concessions, and national protected areas.			Guatemala
	Species Richness	FSC			0,75	Large quantities of forest buffalo and elephants were found in areas logged, and near to protected areas.		Africa	The Republic of Congo
26 Rana et al., 2018	Deforestation	FSC			0,50	The study applied the synthetic control method to evaluate the impact of FSC on a single FMU in each of the three tropical forest landscape, for the time period 2000-2012. Results indicated that FSC reduced the tree cover loss in the most recent year (2012), in all three landscapes.	Tropical	South America; Africa; South-East Asia	Brazil; Gabon; Indonesia.



27 Rivett et al., 2016	Seedling Recruitment		FSC		0,25	Within the Iwokrama forest (FSC certified since 2007),the authors compared an unlogged forest (control), with one 1.5 years, and 4.5 years postharvest forest plots, to understand how RIL affects seedling regeneration. Results showed that RIL had either a neutral or positive impact on the density of seelings of timber species, when compared to unlogged forest.	Tropical	South America	Guyana
28 Simonsson et al., 2016	Areas set-aside	FSC			0,75	The study compared the area extent, structural diversity important to biodiversity, and stand characteristics between FSC certified voluntary set-asides (VSA), formally state-protected nature reserves, and managed production forests.Results showed that VSA are an important factor to complement traditional reserves concerning size and structural factors important to biodiversity.	Boreal	Europe	Sweden
29 Sollmann et al., 2017	Species Richness	FSC			0,75	The study compared three commercially used forests: the Deramakot Forest Reserve (FSC certified since 1997), the Segaliud Lokan Forest Reserve (certified by the Malaysian Timber Certification Scheme in 2009), and the Tangkulap-Pinangah Forest Reserve (FSC certified in 2011, after the study was conducted).The results showed positive impacts of FSC on fauna, but hunting pressure needs to be addressed.	Tropical	South-East Asia	Sabah, Malaysia, Borneo



30 Tobler et al., 2018	Mammal Richness	FSC			0,75	The study investigated terrestrial mammal communities within FSC certified logging concessions in Guatemala and Peru. Results demonstrated that well-managed logging concessions can maintain important populations of large and medium-sized mammals including large herbivores and large carnivores as long as hunting is controlled and timber volumes extracted are low.	Tropical	South America	Guatemala and Peru
31 Tritsch et al., 2016	Forest Disturbance	FSC			0,75	The study compared forest disturbance indicators over a 15 year period of 81 forested plots (logged with RIL following FSC certification, plots conventionally logged, and plots with unknown forest management practices), in the municipality of Paragominas. Results showed that RIL applied under FSC certification helped to reduce logging impacts, in terms of canopy openings.	Tropical	South America	Brazil



APPENDIX C - General overview of the categories examined, the indicators, the biomes, and the impacts of FSC and PEFC.

CATEGORIES	INDICATORS	BOREAL FSC	BOREAL PEFC	TEMPERATE FSC	TEMPERATE PEFC	TROPICAL FSC	TROPICAL PEFC
FLORA	Areas set-aside	22 (CS, Neutral); 11 (CS, Neutral); 10 (CS, Positive); 28 (CS, Positive)	22 (CS, Neutral)				
FLORA	Broad-leaved trees	14 (CS, Positive)	14 (CS, Positive)				
FLORA	Cover, richness and diversity of Mediterranean shrublands			6 (CS, Positive)			
FLORA	Deforestation					25 (R, Positive); 2 (R, Positive); 26 (CS, Positive); 23 (CS, Neutral); 20 (CS, Positive); 1 (CS, Neutral)	
FLORA	Environmentally important areas	22 (CS, Neutral)	22 (CS, Neutral)				
FLORA	Floristic composition					17 (CS, Positive)	
FLORA	Forest disturbance					2 (R, Positive); 20 (CS, Negative); 31 (CS, Positive)	
FLORA	Forest structure					19 (CS, Neutral); 15 (CS, Positive)	
FLORA	Live tree characteristics			12 (CS, Neutral)			
FLORA	Mature stands	18 (CS, Positive)					
FLORA	Old growth forests	14 (CS, Positive)	14 (CS, Positive)				
FLORA	Potential functional habitat connectivity	11 (CS, Neutral); 10 (CS, Positive)					
FLORA	Seedling recruitment					27 (CS, Neutral)	
FLORA	Structural habitat connectivity	11 (CS, Neutral); 10 (CS, Positive)					
FLORA	Structure, composition and diversity of plant communities					3 (CS, Positive)	
FLORA	Tree species richness, diversity and density					2 (R, Positive); 16 (CS, Positive)	
FLORA	Trees and high stumps left in the plots	22 (CS, Neutral)	22 (CS, Neutral)				
FAUNA	Bird species					25 (R, Positive); 8 (CS, Positive)	
FAUNA	Mammal richness					25 (R, Positive); 24 (CS, Positive); 21 (CS, Positive); 8 (CS, Positive); 30 (CS, Positive)	24 (CS, Positive)
FAUNA	Species richness			4 (CS, Positive)		25 (R, Positive); 2 (R, Positive); 29 (CS, Positive)	
ECOSYSTEM SERVICES	Air pollution					20 (CS, Positive)	
ECOSYSTEM SERVICES	Biomass			12 (CS, Negative)			
ECOSYSTEM SERVICES	Carbon emissions					13 (CS, Neutral)	
ECOSYSTEM SERVICES	Carbon storage					7 (CS, Positive)	
ECOSYSTEM SERVICES	Coarse Woody Debris Volumes			12 (CS, Positive)			
ECOSYSTEM SERVICES	Dead wood	14 (CS, Positive)	14 (CS, Positive)				
ECOSYSTEM SERVICES	Ecological condition of Mediterranean streams			5 (CS, Positive)			
ECOSYSTEM SERVICES	Fire incidence					20 (CS, Neutral); 15 (CS, Positive)	
ECOSYSTEM SERVICES	Watershed services					9 (CS, Positive)	

LEGEND

	CASE STUDIES	REVIEWS
Positive	(dark green)	(light green)
Neutral	(yellow-orange)	(light yellow)
Negative	(red)	(orange)

1. Blackman et al., 2015
2. Burivalova et al., 2017
3. De longh et al., 2014
4. Dias et al., 2013
5. Dias et al., 2015
6. Dias et al., 2016
7. ESCD, Indonesia, 2017
8. ESCD, Indonesia, 2017
9. ESCD, Indonesia, 2016
10. Elbakidze et al., 2011
11. Elbakidze et al., 2016
12. Foster at al., 2008
13. Griscom et al., 2014
14. Johansson et al., 2011
15. Kalonga et al., 2015
16. Kalonga et al., 2016
17. Kukkonen et al., 2009
18. Lõhmus et al., 2010
19. Medjibe et al., 2013
20. Miteva et al., 2015
21. Mohamed et al., 2013
22. Nordén et al., 2016
23. Panlasigui et al., 2015
24. Polisar et al., 2017
25. Putz et al., 2010
26. Rana et al., 2018
27. Rivett et al., 2016
28. Simonsson et al., 2016
29. Sollmann et al., 2017
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