Challenges on fire severity assessment in Indonesia: A vegetation diversity changes perspective

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Abstract. Fire severity assessment plays a significant role in post-fire management, which relates to burned area recovery, economic valuation, and law enforcement. Although various fire severity assessments have been conducted in several burned areas in Indonesia, the standardized method seems limited. This study aims to define criteria and indicators for forest and land fire severity assessment based on systematic reviews using a text mining approach. Systematic reviews on peer-reviewed journal articles related to forest fire severity published in 2010-2021 from Google Scholar source was conducted using Publish or Perish application using keywords of forest fire, severity, criteria, indicator, vegetation, soil, wildlife, living trees, mortality, survival, a burned area, abundance with no citations nor patents included. The linkage among forest fire severity related terms was analyzed using the VOSviewer application, which is based on a text mining approach to identify the most common criteria and indicators for fire severity assessment. The study revealed that there are 991 articles published fits to the keywords, of which 269 articles close related to forest fire severity from 75 peer-reviewed journals. Text mining analyses resulted in 4 clusters of forest fire severity related terms. The criteria commonly used for forest fire severity assessment are vegetation and soil, while the options for indicators including diversity, abundance, forest structure, tree mortality, and burn depth. These criteria and indicators are recommended for formulating forest fire severity assessment standard methods in Indonesia.

1. Introduction

Forest and land fires in Indonesia are environmental issues that occur every year for the last two decades. The impacts of the fires include ecological, economic, social and political aspects at the local, national, regional and global levels. According to the Minister of Environment and Forestry's Regulation P.32/MenLHK/Setjen/Kum.1/3/2016 on forest and land fire control, forest fire impact assessment is one of the actions in forest fire control. It is referred to Government Regulation Number 23 of 2021 on Forestry Operations Article 258 verse 2 on the importance of identifying and evaluating forest fire occurrences, which includes gathering data and information about fires, measuring and sketching fire locations, and damage level analyses and recommendations. In comparison to the prevention and containment of forest and land fires, post-fire research and technology development is lagging.
Fire impact assessments are generally carried out for research purposes and forest rehabilitation planning, forest conservation, and law enforcement. However, a standardized fire impacts assessment used as a reference for forest fire control is still minimal. Field assessments vary in methods. One approach in assessing the impact of fires is the fire severity level, which measures the impacts of fire on the ecosystem, including soil, flora, fauna, water, and other ecosystem elements. The magnitude of the impact of fire on ecosystem elements and the environment depends on several factors, namely: fire intensity, fire severity, soil type, rain that falls after the fire, and the extent of the fire [1]. However, recent fire science development shows different fire severity and burned severity definitions that are often used interchangeably [2]. Based on the Glossary of Wildland Fire Terminology [3], Fire severity is a function of fire intensity and resident time. A fire's heat pulse directed toward the ground. Similar to soil heating and duff consumption, buried plant component death is related to burn intensity.

Both phrases refer to elements of fire. Their differences are notable. It depends on the characteristics of the active fire and the immediate post-fire effects on the nearby environment. For the local and regional ecology, burn severity considers both the immediate and long-term repercussions of a fire [4]. After a fire, a study revealed essential factors and a scoring system to distinguish light, medium, or heavy burned areas [5].

The expansion of forest fire severity research has been sporadic and limited. Methods for measuring the intensity of flames have been developed in many forest types around the world. Some countries even have specific criteria for assessing forest fire severity. Were any standard criteria and indicators for assessing forest and land fire severity defined? To get an answer, we used science mapping on forest fire severity publications. Science mapping is the act of evaluating and visualizing domains. It might cover an entire scientific discipline, a research area, or specific issues [6]. This can be done as a systematic review. With the goal of finding and retrieving worldwide evidence relevant to a certain issue or series of questions, as well as analyzing and synthesizing the results, it is broadly described as a type of research synthesis [7]. Today, systematic reviews are conducted for a wide range of purposes across diverse fields of inquiry, different evidence types and different questions [8].

Text mining algorithms have been used in previous studies to detect patterns in text sources. Clustering of text documents was tested on a dataset of IPB University's computer science final projects [9]. The study used the K-Means clustering algorithm with a number of clusters (k) of 10. Furthermore, to examine the association on terms that frequently exist in abstract texts, this study employed the Equivalence CLASS Transformation (ECLAT) algorithm [10], which is an association rule mining tool. On the text documents [11], the Hierarchical Frequent Term based Clustering (HFTC) algorithm [12] was used to extract the hierarchical frequent term. The end consequence is term assassination.

This study aims to define criteria and indicators for forest and land fire severity assessment based on systematic reviews using a text mining approach. Development standardized fire severity assessment is critical as reference for various parties: 1) Academics, beneficial for the development of forest and land fire science, 2) Forestry policymakers, as a basis for rehabilitation planning of the burned area, 3) Forest and land managers, as a basis for action in post-fire management,4) Investigators, as a reference in the process of law enforcement in fire cases.

2. Methodology
A systematic analysis of peer-reviewed research publications on the severity of forest and land fires was done to find, select, and critically appraise pertinent primary research, as well as extract and analyze data from the included studies to address the research question. The systematic review process entails the following steps: source identification, keyword identification, article search utilizing keywords, article classification, and valid article selection. The systematic methodology used in this investigation is depicted in Figure 1.

2.1. Data and tools
Datasets used in the study were free available peer-reviewed research articles on forest and land fire severity published on indexed journals compiled from Google Scholar from 2010 to 2021. Software
used for systematic analyses were Publish or Perish as a search engine to compile journal articles and VOSviewer to classify and clusters the articles based on the text mining approach.

2.2. **Keywords identification, literature searching and classification**

To start searching the literature, combined keywords are identified, including forest fire, severity, criteria, indicator, vegetation, soil, wildlife, living trees, mortality, survival, burned area, and abundance. Literature search with those combined keywords was applied using Publish or Perish software, classifying the articles into cites, ranks, authors, title, journals, publisher, and year. The articles found were then selected for the most relevant articles to the research question. All the irrelevant articles were deleted. The classification process resulted in 991 articles with those combined keywords.

2.3. **Data analyses**

The articles were then analyzed with the following steps:

a. Refining for the most relevant articles by excluding publication types of books, thesis/dissertation, reports, and other non-journal articles.

b. Using additional keywords of “fire” and “burn” to get only forest fire-related articles. This process resulted in 269 peer-reviewed journal articles as the most relevant articles for further analyses.

c. Text mapping using VOSviewer. The selected articles in RIS form file was imported to the software to be analyzed as text data. Maps were created based on a network construct constructed of peer-reviewed journals and terms. Items in these networks can be connected by co-authorship, co-occurrence, citation, bibliographic coupling, or co-citation links. To construct a network, reference manager files (RIS) was used as input to VOSviewer [13]. The object of interest of this study is terms related to forest fire severity or forest fire severity aspects as the item.

d. In depth-analyses was conducted for selected articles from ten most-cited journals to identify criteria and indicator of forest fire severity assessment and finally the standard criteria and indicators for forest fire severity assessment were summarized.

![Figure 1. The systematic process of this study.](image)

3. **Results and discussions**

3.1 **Research trends**

Between 2010 and 2021, several research studies on the intensity of forest fires were published in peer-reviewed international journals. Around 269 peer-reviewed publications have been published in 75 journals, including Forest Ecology and Management, International Journal of Wildland Fire, Fire Ecology, Canadian Journal of Forest Research, and Forests (Table 1). Research on this topic seems to
increase with the highest number of publications found in 2020 (Figure 1). The growing number of research topics may indicate the critical nature of forest fire severity in forest fire management and fire science. However, study on this subject is limited in Indonesia due to the country’s fire circumstances, which might pose a future problem.

Table 1. List of 30 Journal Publications on forest fire-related topic in 2010-2020.

| No. | Journal                           | Total article | No. | Journal                        | Total article |
|-----|-----------------------------------|---------------|-----|--------------------------------|---------------|
| 1   | Forest Ecology and Management     | 58            | 16  | Journal of Mammalogy           | 3             |
|     | International Journal of Wildland Fire | 46           | 17  | Natural Areas Journal          | 3             |
| 3   | Fire Ecology                      | 16            | 18  | Environment                    | 3             |
|     | Canadian Journal of Forest Research | 13           | 19  | Environment                    | 3             |
| 5   | Forests                           | 12            | 20  | The Rangeland Journal          | 3             |
| 6   | PloS one                          | 8             | 21  | Forest Science                 | 2             |
| 7   | Ecological Applications           | 7             | 22  | Freshwater Science             | 2             |
|     |                                   |               |     | Frontiers in Ecology and       |               |
|     |                                   |               |     | Evolution                      |               |
| 8   | Ecosphere                         | 6             | 23  | Journal of Biogeography        | 2             |
| 9   | Remote Sensing                    | 5             | 24  | Frontiers in Plant Science     | 2             |
| 10  | Botany                            | 4             | 25  |                                |               |
|     | Biodiversity and conservation     |               |     |                                |               |
| 11  | Ecosystems                        | 3             | 26  | New Forests                    | 2             |
| 12  | Environmental entomology          | 3             | 27  | Sustainability                 | 2             |
| 13  | Fire                              | 3             | 28  | The Holocene                   | 2             |
| 14  | Journal of Ecology                | 3             | 29  | Trees                          | 2             |
| 15  |                                   | 3             | 30  | Wildlife Research              | 2             |

Figure 2. Number of articles related to forest fire severity published in peer-reviewed journals in the 2010-2021 period.
3.2. Criteria and indicator

The severity of fire has a substantial effect on how ecosystems adapt to fire, meaning that forest management practices have an effect on the impact of high intensity fires on ecosystems [14]. Fire severity was a key factor influencing all ecosystem components and controlling post-fire biomass accumulation. The words "fire severity" and "burn severity" have recently changed usage, causing significant confusion. Some authors explain this by defining fire severity as the environmental implications of fire, which are subjective. Experiments have determined that the loss or change in organic matter above and below ground is a measure of fire severity. Confusion arises when ecological effects are included in the definition of fire or burn severity. These include soil erosion, plant regeneration, community structure restoration, and faunal recolonization [15]. Three primary factors affecting burn severity (i.e., the fire triangle) are topography (e.g., elevation, slope, aspect, topographic position, solar radiation, and topographic wetness), weather (e.g., temperature, relative moisture, wind speed, drought factor, and regional climate), and fuel (e.g., forest cover type, composition and configuration of forest, shrubs, heterogeneity, and tree densities) [2].

Text mining with VOSviewer produces network representation of fire severity (Figure 3). In general, the closer two terms are placed together, the closer they are connected. The distance between two items determines their strength. A closer relationship suggests a shorter gap. Lines connect the most significant sentences that connect the various components of fire severity [8] and forms clusters. Recent studies have involved in spatial multidimensional association rules mining in forest fire data [16].

Clustering as a process of grouping together entities from an ensemble into classes of entities that are similar in some sense has been applied in bibliographical studies. The clustering algorithms have been used in grouping the text documents to extract interesting patterns from the documents [9, 17, 18]. The study revealed that there are four clusters of terms related to forest fire severity, namely:
Cluster 1: fire severity, composition, area, site, diversity, fire history, post-fire, abundance
Cluster 2: impacts, forest fire, tree mortality, species, biodiversity, fauna, fire regime
Cluster 3: vegetation, ecosystem, burned forest, fire effect
Cluster 4: tree, forest ecosystem, soil, forest structure

These clusters reflect the relatedness of fire severity aspects, which are possible as criteria and indicators. The forest fire severity criteria derived from these clusters are area, fauna, vegetation, and soil. Meanwhile, there are some options for forest fire severity indicators, including diversity, abundance, tree mortality, species, forest structure (Table 2).
Figure 3. Network visualization of forest fire severity aspects.

Table 2. Options for criteria and indicators of forest fire severity.

| Clusters | Item | Criteria option | Indicator option |
|----------|------|-----------------|------------------|
| 1        | fire severity, composition, area, site, diversity, fire history, post-fire, abundance | area | diversity, abundance |
| 2        | impacts, forest fire, tree mortality, species, biodiversity, fauna, fire regime | biodiversity, fauna | tree mortality, species |
| 3        | vegetation, ecosystem, burned forest, fire effect | vegetation | burned forest |
| 4        | tree, forest ecosystem, soil, forest structure | soil, tree | forest structure |

The item density visualization from VOSviewer matches the network visualization. Each point is colored by the density of items there. The study's colors range from blue to green to yellow and red. The more stuff around a point and the heavier those items are, the closer the point's hue gets to red. The color of a point is closer to blue when there are fewer objects nearby and their weights are lower. The main findings of this study include severity, impact, species, ecosystem, and area.
Based on content analysis, different countries utilize different fire severity thresholds. The USA, Canada, and Australia all have standardized fire severity/burned severity assessments. Indicators included vegetation and soil. However, the assessment markers differ by forest type, ecosystem type, and climate. As in the USA, vegetation (foliage, twigs, branches) and substrate (litter, duff, soil) are employed as indicators [3], burned depth and fuel consumption are included as indicators in Russia.

Similarly, to how fire responses vary according to forest habitat type, the research criteria and indicators are different. The leaf litter has been consumed, resulting in a coarse, light-colored ash; the duff has been thoroughly burnt; the leaves and smaller twigs have been completely destroyed, but shrub branches have remained relatively undamaged (40 percent of the shrub canopy is consumed) [3]; fine and large fuel loads, increased diversity of understory vegetation [9]; fuel loads, and vegetation structure and composition [14,15] advocated using the amount of biomass consumed instead of plant mortality, and [19]used changes in height to measure severity in shrublands. Surface fuel consumption has also been used as an essential indicator of severity [20,21]; and stand composition and structural characteristics (i.e., snag and veteran tree densities, tree size variability, and maximum tree size) at mixed-severity and high-severity locations following recent (<150 years) and older (≥150 years) stand-replacing fires [22].

In Indonesia, fire impacts assessment is a newer research issue than in Australia, Canada, Europe, and the USA. Studies focus on changes in flora and wildlife. However, the study seems to be rather limited. Since 2004-2005, damage to flora and soil has been used to quantify the severity of forest fires. It has been used to assess the impact of fires. The Fire Severity technique is shown to be the most appropriate approach for assessing fire impacts in Indonesia. This method has been used on mineral and peat soils in Java and outside Java (Sumatra and Kalimantan) [23–27]. However, various criteria and indicators are found.

Fire and burn severity can be measured in the field using any one or a combination of variables (top). Indicators of severity from remote sensing (side). We examine remote sensing applications for assessing fire severity and burn severity. For example, monitoring post-fire vegetation recovery is one of the many applications of fire risk mapping. Many environmental characteristics linked with fire activity can be mapped, evaluated, and monitored using multispectral sensors, lidar, and emerging
unmanned aerial systems (UAS) [28]. Standing dead trees (snags) are critical indicators of forest biodiversity and ecosystem health, and Airborne Laser Scanning (ALS) has the ability to detect and analyze conifer snags. These metrics describe important habitat components for a variety of endangered wildlife species [29]. For the unburned, low, and high classes, producer and user accuracies exceeded 80% for the unburned, low, and high classes, utilizing Landsat-5 Thematic Mapper (TM) time-series pictures. User and producer accuracies were shown to be lower for intermediate burn severity [30]. These findings support a model comparable to the widely used differenced normalized burn ratio for near-infrared and two short wave infrared bands (NBR). The most parsimonious model, according to Akaike's Information Criteria, is the difference in MODIS channel 6 (1628–1652 nm) between pre- and post-fire conditions. The models can be used to map fire severity in northern Australia's fire-prone tropical savanna vegetation [31].

For future challenges, remote sensing technologies provide a low-cost, multi-temporal method for conducting research on fire ecology at the local, regional, and global scales. Current research is advancing at a breakneck pace, incorporating new technologies and techniques that improve accuracy and efficiency [28]. The term "burn severity" refers to the magnitude of change in vegetation reflectance in the pre- and post-fire satellite photos used in this investigation. The delta normalized burn ratio (dNBR) is the change in near-infrared reflectance between pre- and post-fire satellite images. It has been effectively utilized to measure burn severity in a number of forest fire investigations [2]. A proof-of-concept for using low-cost UAV photogrammetric mapping to assess important parameters of boreal burn intensity at landscape sizes has been made [32].

We examine the challenges of assessing field fire severity using remote sensing and simulation models. For objective severity assessment, it is advocated that fire impacts be assessed directly rather than condensed into a single severity score [33]. This approach is effective and interpretable only when the index is associated with ground-level fire impacts.

4. Conclusions
There are about 269 forest fire severity related articles from 75 peer-reviewed journals published in 2010-2021. Four clusters of forest fire severity aspects were produced by text mining analyses using VOSviewer, where fire severity is close to composition, area, site, diversity, fire history, post-fire, and abundance. The most essential forest fire severity aspects were: severity, impact, species, ecosystem, and area. The criteria commonly used for forest fire severity assessment are vegetation and soil, while the options for indicators including diversity, abundance, forest structure, tree mortality, and burned depth. Further research on the formulation of criteria and indicators of forest fire severity need to be elaborated.

Acknowledgements
The authors wish to thank the Ministry of Education, Culture, Research, and Technology for financial support through The Master Thesis Research Scheme (PTM) and The Committee of The 2nd Biennial Conference on Tropical Biodiversity for the opportunity to present this paper at the conference.

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