Natural Resources Conservation and Research 2024, 7(1), 4353.
https://doi.org/10.24294/nrcr.v7i1.4353

Review

Methods for economic assessment of forest resource degradation: A systematic review

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CITATION

Sourokou R, Vodouhe FG, Yabi JA. Methods for economic assessment of forest resource degradation: A systematic review. Natural Resources Conservation and Research. 2024; 7(1): 4353. https://doi.org/10.24294/nrcr.v7i1.4353

ARTICLE INFO

Received: 24 January 2024
Accepted: 18 February 2024
Available online: 15 March 2024

Abstract: Forest degradation is one of the challenges facing the planet today. Several methods have been used to measure forest degradation, including spatiotemporal model analysis, satellite analysis, remote sensing, time series data, geospatial techniques, and most recently aerial drone imagery. However, few studies have used economic valuation methods to assess forest degradation. Therefore, this research aimed to identify the methods used the economic assessment of forest degradation. This systematic review was carried out using PRISMA guidelines. Research articles on the economic valuation of forest resource loss, published from 2015 to 2022, were electronically collected from three databases. Three independent reviewers, with the third acting as referee, inventoried articles, extracted data, and assessed the risk of bias in the articles included in the study. A total of 10,095 articles were identified, including one article from the grey literature. Only five articles met the eligibility criteria. A qualitative content analysis was performed on the extracted data. The selected articles used various methods. However, only a few articles used the contingent valuation method, even though this is indicated for estimating the highest economic value of forests. Based on forest functions, the articles evaluated erosion due to the absence of trees, wood loss, recreation areas and externalities due to forest loss, air quality, water regulation, food supply, and wildlife. The main limitation of this review was the small number of studies included, which may have affected the findings. The study protocol is registered in PROSPERO under the number CRD42021223242.

Keywords: economic assessment; deforestation; contingent valuation; natural resources; PRISMA

1. Introduction

Global forests provide a multitude of ecosystem services (ES) for human well-being [1,2]. Conservation of the forest ecosystem is fundamental to economic and ecological sustainability [3]. In fact, local livelihoods depend on forest resources. Therefore, sustainable use of forest resources contributes to improving local incomes, hence the need to make its exploitation sustainable. Forests, in general, and tropical forests, in particular, play a vital and well-known role due to the ESs they provide [4]. Unfortunately, these valuable natural resources face many threats, especially deforestation and forest degradation [5–7]. However, there are different definitions of these two threats in the literature. Therefore, we define deforestation as a decrease in the area covered by a forest, and forest degradation as not only a reduction in the area of the forest but also a decrease in the ESs it provides. In this study, we did not consider the difference between these two terminologies. Therefore, it is clear that healthy forests are at risk, in the context of global changes, from increasing temperatures and extreme climatic events [8]. Ecosystem degradation and biodiversity loss affect the proper functioning and resilience of ecosystems and, thus, threaten their capacity to provide a continuous flow of ESs to present and future generations [9]. Around the world, deforestation is a problem [10], and much of the loss of global biodiversity and other ESs results from human-induced degradation and deforestation [11]. The UN has set environmental targets, urging action to combat climate change and its repercussions (Sustainable Development Goal 13), even though these targets are negatively impacted by the creation of strong institutions and economic growth [12].

Several studies have focused on the measurement of forest degradation around the world. For example, Borges et al. [13] used time series data to assess forest loss in Tanzania and Eastwood et al. [14] used similar data to identify the causes of ecosystem function loss and predict the future of ESs under different climate and pollution scenarios. The natural resource to which this study applied was the watershed. One study in Mexico used economic valuation to measure the loss of coastal ESs [15]. An economic approach was applied to coastal ecosystems, which are not exactly forest resources. Furthermore, Hiltner et al. [16] focused on the importance of forest condition in estimating biomass losses from tropical forests. The method used was based on an analysis of tree loss detection in forest areas using a time series of aerial images acquired by drone. Similarly, Ouattara et al. [17] used aerial images taken by drones to detect the loss of forest trees in Côte d'Ivoire. Another study performed a global meta-analysis using dung beetles as indicator taxa [18]. This meta-analysis looked at how the loss and degradation of primary forests reduced biodiversity and ecosystem functioning. Although this study focused on forests, dung beetles were used as indicators because of their sensitivity to anthropogenic disturbance and their importance in performing essential ecological functions in terrestrial ecosystems. Another study used spatio-temporal dynamics analysis using Landsat images and a supervised random forest classifier to measure the transformation of rural landscapes in the Vietnamese Mekong Delta [19]. Finally, Sugimoto et al. [20] used scattering power decomposition and optimal averaging of volume scattering power in tropical rainforest regions to assess deforestation.

One observation about these studies is that either the resource being evaluated was not a forest or the methodology used was not an economic valuation. Most of these studies used spatiotemporal model analyses, satellite, remote sensing, time series data, and geospatial techniques as assessment methods [21–27]. However, few works have used economic valuation methods to assess forest degradation.

Monetary valuation of biodiversity has a triple benefit: it informs decisions that maximize well-being, provides a means to set trading targets, and is effective in attracting the attention of policymakers [28]. Estimates of economic costs and benefits of land-use options can inform decision making about the multiple benefits that biodiversity and ecosystems provide to human well-being as well as about the economic consequences of ecosystem loss [29]. Moreover, systematic reviews focusing on the economic valuation of forest degradation are few in number despite a revival of this method in recent decades [2]. The study by Förster et al. [30], which is the only systematic review to allude to cost assessment, covered all ESs. Thus, to our knowledge, there has been no systematic review that deals with an economic valuation exclusively on forest loss. Therefore, our study used the Preferred Reporting Items for

Systematic Reviews and Meta-Analyses (PRISMA) guidelines to perform an economic valuation of forest clearance. We have identified the latest studies in the field from around the world, which is the contribution of our research.

Systematic reviews and meta-analyses are essential tools for summarizing evidence in an accurate and reliable manner [31]. A systematic review of the literature is a qualitative research method that aims to gather all empirical evidence meeting predefined eligibility criteria to answer specific research questions [32]. It provides knowledge from multiple articles. Thus, a systematic review can give an in-depth global view of a research question. A systematic review of economic valuation includes the determination of the utilitarian concept of value, incorporating ethical and social dimensions [33], and a consideration of use and non-use values [2]. Economic valuation takes into account sustainability and social and environmental aspects. Therefore, economic valuation can play an important role in guiding optimal decision making and correcting imbalances between environmental management and economic development [34], particularly because policymakers are more sensitive to economic data.

This study aimed to identify how researchers assess the economic value of forest degradation. A systematic review generally follows a four-step process: identification, review, eligibility, and inclusion [31]. Specifically, this involves i) identifying studies in the selected research databases and eliminating duplicates, ii) examining identified studies on the basis of titles and abstracts, iii) selecting articles after evaluation of the full texts, and iv) selecting those that meet all the eligibility criteria. The study was indifferent to the populations chosen because these depend on the economic method used, and it did not make a comparison between groups (treated and untreated). All types of economic valuation studies were considered, but the included studies were based on the economic valuation of the loss of natural or related resources. Preference was given to deforestation. We conducted searches of three databases from November 2020 to September 2021 and updated in February 2023. The extracted data were the full references of the included studies, their methodology, and their main findings. All this information will be described in a narrative.

2. Materials and methods

2.1. Protocol and registration

This systematic review was registered in PROSPERO as CRD42021223242. The practice of systematic review is used in several disciplines, including environmental conservation and management [35,36]. Here, it will be applied to the assessment of forest degradation. We used the PRISMA guidelines [31] through its four steps: identification, review, eligibility, and inclusion (articles included in the study).

2.2. Eligibility criteria

Searches were conducted from November 2020 to September 2021 and updated in February 2023 for articles on the economic valuation of natural resource loss, particularly forests. The identified articles have been published in all languages as of 2015. To answer the research question of how researchers estimate the economic value of forest degradation, the population, intervention, comparison, outcome/output, study design (PICOS) approach was used to identify the eligibility criteria (**Table 1**).

Table 1. Population, intervention, comparison, outcome/output, study design (PICOS).

Category	Results
Population	Population selected to assess the loss of natural resources
Intervention	Any type of study on economic valuation
Comparison	The study will not make a comparison between groups (treated vs. untreated)
Outcome/output	Full reference study (author names, country, study identity and publication year, document type, journal), methodology (valuation method, sample size, sample characteristics, model, settings, area of study site, location, year of valuation, underlying assumptions), monetary value (minimum, mean, median, maximum), valuation (type of prospective assessment or retrospective evaluation, type of natural resources assessed, nature of valuation)
Study design	The studies included were those based on an economic valuation of the loss of natural resources. Preference was given to deforestation

2.3. Data source

Articles were selected electronically from three different databases: Web of Science, Scopus, and Environment Index. Keywords were searched in the article title, abstract, and subjects. These keywords were (“economic valuation” OR “economic analysis” OR “economic assessment”) AND (“deforestation” OR “forest degradation” OR “natural resources loss” OR “forest loss”). In addition, reports of congresses or conferences dealing with the subject were used. References from the included articles were also used. At the end of this step, several articles were identified.

2.4. Study selection

Two independent reviewers evaluated all the identified articles. Discrepancies were discussed, and a third reviewer acted as an arbitrator in case of non-consensus. The identified articles were exported to Zotero and to the Colandr application. Duplicates were eliminated. The next step was to review the titles and abstracts. Articles on irrelevant topics were rejected. Then, the full texts of the articles were carefully reviewed to select eligible articles. The included articles were those whose methodology and nature of the natural resources (in this case, forests) were deemed to be consistent. Descriptive statistics were used to access the data.

2.5. Data extraction

The two independent reviewers extracted relevant data from all included articles. The extracts were compared, and any differences were checked and resolved through discussion. The following information was extracted: full study references (author names, country, article title, year of publication, type of article, and journal), methodology (study area, type of natural resources evaluated, sample size and characteristics, type and nature of evaluation, evaluation methodology, models, parameters, and basic assumptions, if applicable), and results (monetary and other values).

The two reviewers used appropriate tools to assess independently the risk of bias in the studies. Disagreements were discussed by both reviewers and resolved by a third when necessary.

2.6. Risk of bias in individual studies

The risk of bias in individual studies was assessed and discussed in the results section (in particular in 3.3. Risk of bias within studies).

2.7. Synthesis of results

We used the Colandr database to include or exclude studies according to the eligibility criteria. Results of the included articles that were not suitable for a meta-analysis (i.e., qualitative results) are summarized in a table created for this purpose for each study. Information was extracted from each study to describe the economic valuation of forest degradation.

2.8. Risk of bias in the overall studies

We assessed the different risks of bias, namely publication bias (omission of studies), selection report bias (omission of results), omission of summary data, and omission of participants using the Cochrane risk of bias assessment tool [37].

3. Results

3.1. Studies selected

A total of 10,095 articles were identified from the database search (**Figure 1**). After rejecting 1251 duplicate articles, the titles and abstracts of the remaining 8844 articles were examined by the two reviewers for their relevance to the economic valuation of forest degradation. It was found that 44 articles were deemed eligible. The full text of these 44 articles was examined with a fine-tooth comb, and 32 articles were rejected because of the evaluation method (non-economic evaluation), five articles were excluded because of a non-compliant evaluation object, and two articles were rejected because of the evaluated natural resource was not a forest. Finally, five articles including a systematic review were included in the study: one article published in 2016, one in 2017, one in 2019, and two in 2021.

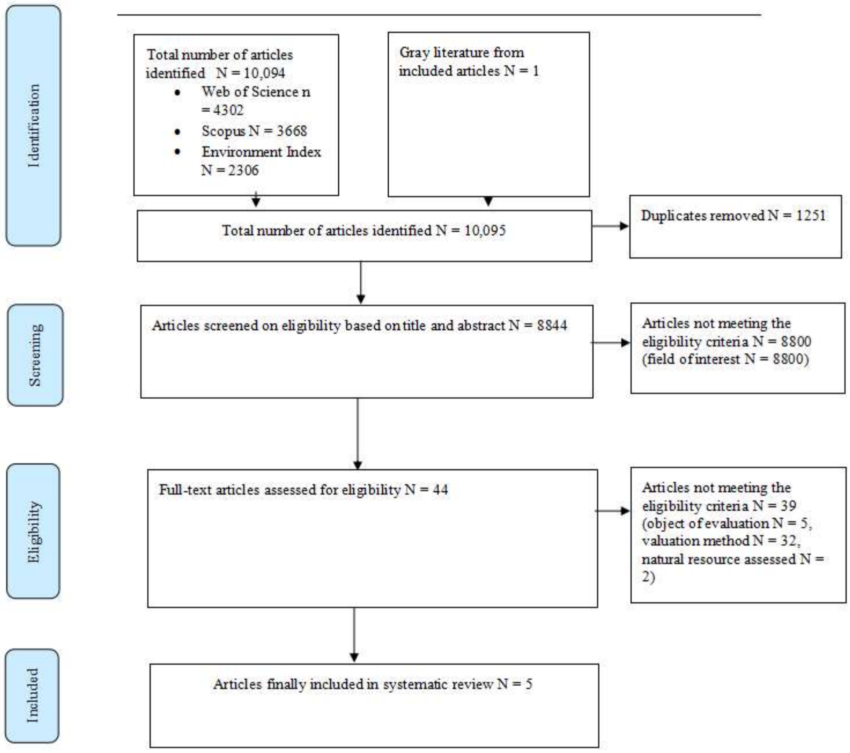

Figure 1. Flow chart of the literature search and selection process for a systematic review of the economic valuation of forest degradation.

3.2. Characteristics of the studies

At the end of the process, the five studies selected were [30,38–41]. The characteristics of these studies are summarized in **Tables 2** and **3** through the extraction of their data.

Table 2. Data extraction from selected articles.

Study						Population				Intervention and comparison	
Study title	**Document type**	**First author**	**Year pub**	**Journal**	**Country**	**Study area**	**Natural resources assessed**	**Sample characteristics**	**Sample size**	**Valuation type**	**Nature of evaluation**
Integration of different environmental valuation methods to estimate forest degradation in arid and semi-arid regions	Article	Mohammad Majdalawi	2016	International Journal of Sustainable Development & World Ecology	Jordan	Northern Jordan: Ajloun and Debeen	Forest	Arid and semi-arid zone	53% of Jordan's forest cover	Prospective: 2014 baseline year; 2,044 (30 years) and 2,114 (100 years) assessments	Erosion assessment Evaluation of the value of lost recreation areas Assessment of income from lost timber Assessment of expected loss of forest area (ha) Assessment of expected loss/damage of forests (reforestation)
Valuation of terrestrial and marine biodiversity losses caused by forest wildfire	Article	Roi Durán-Medraño	2017	Journal of Behavioral and Experimental Economics	Spain	University of Vigo	Terrestrial and marine biodiversity	Social science students (Economics, Finance, Tourism, Human Resources Management) with 33% male and 67% female. No natural science students were included. 66% of the sample came from urban areas and the rest from rural areas. More than 50% practiced recreational activities in the areas, and 15% did recreation in the forest areas	240 individuals	Retrospective assessment	Assessment through externalities related to forest fires (loss of forest biomass, increase in forest pests and diseases, loss and displacement of local wildlife, soil erosion, and loss of marine biodiversity)
Incorporating environmental costs of ecosystem service loss in political decision making: A synthesis of monetary values for Germany. NB: We retained the part relating to the loss of tropical forest	Review	Johannes Förster	2019	PLoS ONE	Germany	11 Databases: Externalities Data Review; Environmental Valuation Database; Marine Ecosystem Service Database Environmental Valuation Database; Marine Ecosystem Service Marine Ecosystems; Partnership for Environment and Recreation (non-market); Partnership for Environment and Recreation and Recreation (non-market) Values-Valuation Studies; National Ocean Economics Program; Ecosystem Service Valuation Database; Web of Science; Datenbank "Dokumentation Natur und Landschaft- online"; Karlsruhe Virtueller Katalog; Ojea et al. [1].	Forests and wetlands	109 monetary valuation studies of regulatory and cultural ecosystem services (ES)	6 of 109 selected articles fulfilled the quality criteria	Retrospective assessment	Loss of ESs due to conversion of tropical rainforest to grassland or arable land

Table 2. (*Continued*).

Study						Population				Intervention and comparison	
Study title	**Document type**	**First author**	**Year pub**	**Journal**	**Country**	**Study area**	**Natural resources assessed**	**Sample characteristics**	**Sample size**	**Valuation type**	**Nature of evaluation**
Forest fires and losses caused by fires—an economic approach	Article	Beata Sadowska	2021	WSEAS Transactions on Environment and Development	Selected European countries, including Poland	Forest fires in selected European countries, including Poland	Forest	All forest fires in selected European countries, including Poland	All wildfire statistics published between 2014 and 2018 and state forest financial and economic reports for the same period	Retrospective assessment	Assessment of the area and value of forests lost to fire in selected European countries, including Poland
Economic losses from natural disturbances in Norway spruce forests—a quantification using Monte-Carlo simulations	Article	Thomas Knoke	2021	Ecological Economics	Norway	Spruce forests	Forest	Land with associated spruce stands with different rotation periods	1 ha of spruce plantation	Prospective assessment for 1,000 years	Assessment of economic losses related to climate change through natural disturbances. The sensitivity of economic losses was obtained by assessing changes in expected land value in consideration of standing timber volume and worst-case values for economic return

Table 3. Data extraction from selected articles (continued).

Intervention and comparaison					Outcome
Study	**Nature of valuation**	**Valuation method**	**Model**	**Settings (parameters)**	
Majdalawi et al. 2016	Erosion assessment (1)	Productivity method: This method is used to provide an alternative estimate of damages such as yields that are affected. It is used to estimate the economic value of ecosystem products or services that contribute to production. It is based on a comparison of yields before and after a crisis to show that they have declined over time. Thus, changes in the quantity or quality of a resource will lead to changes in the production and/or productivity of other inputs and may affect the price and/or quantity supplied of the final good [42].		Baseline year 2014 Cost of soil erosion (from previous studies) = 30 JD (Jordanian Dinar)/ha	
	Assessment of the value of lost recreation areas (2)	Transportation cost method		Baseline year 2014 Cost of loss of recreation areas (according to World Bank studies in 2004) = 84 JD/ha After taking inflation into account, this amount was 180 JD/ha in 2014	

Table 3. (*Continued*).

Intervention and comparaison					Outcome
Study	**Nature of valuation**	**Valuation method**	**Model**	**Settings (parameters)**	
	Evaluation of the income from the loss of wood (3)	The study area had 5 forest types for which the distribution of tree species and the estimated wood production of each type were known (previous studies)		Baseline year 2014 Number of trees/ha: 250 Amount of wood (in m^3/tree) produced by each type of forest and tree was known Price of wood was known (see market price)	
	(4) = (1) + (2) + (3)				Expected value in 2044 (30 years) in million JD = 379 ($1 = 0.71 DJ) Expected value in 2114 (100 years) in million JD = 31,624
	Estimated loss of forest area (ha) (5)	A growth rate method was used to estimate the future decline of natural forest areas as a degradation rate. The logarithms of the two values were calculated, and the degradation rate was estimated by finding the difference between the two logarithmic values and dividing the difference by 64 years (2014–1950). As a result, the degradation rate was approximately 0.7%. Based on the rate of forest degradation, the area of forest lost was estimated for each year considering the fact that forest once lost is a reduction in value for all subsequent years. Because of this, the total losses of the forest were estimated by the sum of the losses of each year with those of the previous years (by capitalization)		Baseline year 2014 Degradation rate 0.7% (rate obtained by using the logarithm of the two values: area of forest lost between 1950 and 2014 and growth rate	Expected value in 2044 (30 years) = 54,056 ha Expected value in 2114 (100 years) = 509,087 ha
	Assessment of expected loss/damage of forests (reforestation) (6)	The habitat or resource equivalency analysis (HEA or REA): This methodology allows the benefits of the use and non-use of environmental resources to be captured through its principle of providing services for lost services and compensation for natural resource damages [43]. The main concept behind the AEM method is that the public can be compensated for resource losses through replacement or restoration projects that provide additional resources of the same type, in this case by assuming that the forest area will be replaced by a new forest (reforestation) and its value will be considered the value of the compensation.		Baseline year 2014 Annual discount rate 8% Assumption: restoration will take place every following year to immediately recover the degraded area Value of restoration according to previous studies = 6000 JD/ha in 2004 Lost forest area: accounting for inflation this amount is 15,000 JD/ha in 2014	Expected value in 2044 (30 years) in million JD = 217 Expected value in 2114 (100 years) in million JD = 11,422
	(4) + (6) and taking into account (5)				Expected value in 2044 (30 years) in million JD = 596 ($1 = 0.71 JD) Expected value in 2114 (100 years) in million JD = 43,046

Table 3. (*Continued*).

Intervention and comparaison					**Outcome**
Study	**Nature of valuation**	**Valuation method**	**Model**	**Settings (parameters)**	
Durán-Medraño et al. 2017	Assessment through externalities related to forest fires (loss of forest biomass, increase in forest pests and diseases, loss and displacement of local wildlife, soil erosion, and loss of marine biodiversity)	Discrete choice experiment (DCE), which is a stated preference method based on individual preferences. In DCE studies, individuals choose between several hypothetical programs that affect their well-being. The willingness-to-pay method is used as part of the DCE model. Individuals are asked, on the basis of a questionnaire, how many hours they are willing to work to protect the forest as well as their hourly rate.	(1) $U_{njt} = -\alpha_n p_{njt} + \beta'_n x_{njt} + \varepsilon_{njt}$ $Var(\varepsilon_{njt}) = k_n^2(\frac{\pi^2}{6})$ Dividing Equation (1) by the scale parameter k_n, we have (2) $U_{njt} = -\lambda_n p_{njt} + c'_n x_{njt} + \varepsilon_{njt}'$ (3) $U_{njt} = -\lambda_n p_{njt} + (\lambda_n \omega_n)'_n x_{njt} + \varepsilon_{njt}'$	U is the utility that a decision maker *n* derives from choosing alternative *j* in choice set *t* and is a function of cost *p* and a set of non-cost attributes x; α_n and β_n vary randomly over the decision makers, thus incorporating heterogeneity, and the error term, ε_{njt}, is iid. It is assumed that ε_{njt} is a distributed extreme value and the variance of njt of ε can be different for different decision makers $Var(\varepsilon_{njt}) = k_n^2(\frac{\pi^2}{6})$, where k_n is the scalig parameter for *n* decision makers (1) λ_n= (α_n/k_n), $c_n = (\beta_n/k_n)$ and ε_{njt}' iid standard at an extreme value with constant variance $\frac{\pi^2}{6}$ (2) Because the WTP for an attribute is the ratio of the attribute coefficient and the price coefficient $\omega_n = (c_n/\lambda_n)$, then the utility function can be rewritten as (3)	The average value in number of working days was 10 days for an average monetary value of €400 per individual ($1 = €0.84 in 2017)
Förster et al. 2019	Loss of ecosystem services due to conversion of tropical rainforest into grassland or arable land	Criteria have been identified to assess the adequacy of valuation studies to derive cost estimates for loss of ecosystem services (ES): a. The focus of the valuation study was on the loss of ESs associated with the conversion of tropical rainforest into grassland or arable land; b. There was an explicit description of the biophysical and socio-economic context; c. Transparent study design, methods, and underlying assumptions; d. Monetary values referred to a distinct and clearly identifiable ES or set of ESs; e. Monetary values were derived using common valuation methods (cost-based or benefit-based approaches); f. Monetary values were expressed in €/ha or allowed for currency conversion and unit adjustment; g. Representativeness of monetary values: the reasoning for the minimum–maximum ranges of values was explained by a minimum–maximum range in biophysical or socio-economic factors (e.g., ecosystem carbon content/ha). Monetary values were adjusted for inflation to 2014 values using the Consumer Price Index. Values were adjusted to Purchasing Power Parity. Values were converted to groups of similar units (€/ha/year; €/ha; €/person/year; other)	$Value\ in\ €_{2014} = Value_{deferred} * \frac{CPI_{2014}}{CPI_{Valuation\ year}}$ $Value\ in\ €_{2014} = Value_{2014} * \frac{PPP_{Germany}}{PPP_{Valuation\ year}}$	CPI: Consumer Price Index PPP: Purchasing Power Parity	Most monetary values come from valuation studies that apply a combination of valuation methods. The use of replacement costs as a means of valuing ESs is a common approach in Germany, followed by choice experiments. In tropical regions, willingness-to-pay and market price methods dominate. The database contained 171 monetary values for tropical forest ESs from a total of 23 monetary valuation studies. Of the 171 monetary values, 114 met the criteria for transparency of study design and methods. Five aggregate monetary values met the previous criteria with more relevance to the possible costs involved in the loss or degradation of ESs

Table 3. (*Continued*).

Intervention and comparaison					Outcome
Study	**Nature of valuation**	**Valuation method**	**Model**	**Settings (parameters)**	
Sadowska et al. 2021	Assessment of the area and value of forests lost to fire in Europe including Poland	Critical analysis of the literature on the subject Literature search method Comparative method Method of induction and synthesis Techniques of graphic presentation of data	LFV= (IEV − IV) × L × A × P or LFV = VCI × L × A × P	LFV: Lost forest value in Polish currency; IEV: Index of expected value of 1 ha of standing timber at the age of the tank well; IV: Index of the value of a hectare of standing timber at the age of early felling of this stand; CVI: Value of costs incurred to establish and maintain 1 ha of stand; L: Stand stocking level, which is the quotient of the actual stand volume of trees at the early felling age and the potentially achievable stand volume; A: Area of the stand burned (ha) P: Current official selling price of 1 m^3 of wood in Poland	The economic value of fire losses in Poland varied over the years analyzed, with the highest values in 2015 (6.6 million Zloty), and the lowest in 2017 (1.3 million Zloty). 2018 saw an upward trend with 4.8 million Zloty. ($1 = 3.93 Zloty)
Knoke et al. 2021	Assessment of economic losses related to climate change through natural disturbances. The sensitivity of economic losses was obtained by assessing changes in expected land value in consideration of standing timber volume and worst-case values for economic return	Monte-Carlo simulation method (MCSM). MSMC is a common method to quantify uncertainties based on random experiments in order to estimate the possible ranges and distributions of, for example, future ecological or financial data. To calculate the expected land values, a finite, but very long-time horizon (1000 years) was defined. Over this period, damages caused by natural disturbances as well as stochastic events were simulated. To obtain the economic returns of the Norway spruce, a simulation of the net revenue streams over the 1000 years for each of 20,000 Monte-Carlo iterations. Then, these revenues were discounted and their sum calculated per iteration. To approximate the expected value for the economic criteria, the arithmetic mean of all 20,000 iterations was used. Sets of these simulations (each with 20,000 iterations) for a range of possible rotation periods, T = 30, 40, 50, 60, 70, 80, 90, 100, and 110 years, respectively, were used to find the optimal rotation period. The optimal rotation was identified as the one that maximized the average land expectancy over all iterations. The maximum value of the land expectancy was used to derive the possible economic losses due to disturbance	$R_i = \sum_{t=a}^{T+a} n_{ti}. b^t with b = (1+d)^{-1}, \forall p \in P, c \in C$ $R = E(R) \backsimeq \frac{1}{n}\sum_{i=i}^{n} R_i$ If $a = 0$, then R = ELV If $a > 0$, then R = FV	Ri: Economic return in €/ha for the iteration i; t: Time in years; a: Age of the forest in years; if a = 0, we have the expected land value (ELV) for bare land without standing timber; if $a > 0$, we have the forest value (FV); T: Period of consideration in years (T = 1000 in this study); n_t: Net income flow in €/ha at time t; b^t: Discount factor or coefficient; p: Period of rotation considered; P: Set of rotation periods; c: Age class considered; C: Set of age classes; E(.): Expected value; n: Number of Monte-Carlo simulations (n = 20,000 in this study); i: Index of individual Monte-Carlo simulations (iterations); d: Discount factor (d = 0.015 in this study); ELV: Expected land value; FV: forest value, the sum of ELV and standing timber value	Economic losses induced by disturbances varied considerably, depending on the valuation approach applied: -€2611 to −€34,416 (in 2021; $1 = €0.88). After accounting for extreme events and the impact of disturbances on standing timber, losses were 262 to 1218% higher than the damages derived from standard valuation approaches that neglect these aspects

3.3. Risk of bias within studies

To reduce bias, two reviewers set up and used appropriate tools such as Colandr and Zotero to examine independently the risk of bias in the studies. Disagreements were discussed by both reviewers and addressed by a third when necessary.

3.4. Risk of bias in the overall studies

To reduce the overall publication risk, the studies searched in the databases were restricted to articles, journals, conference reports, or conference proceedings. We are aware that beyond this provision, entire studies may be missing from our analysis if they were never published, published in obscure locations, or inappropriately indexed in the databases. For the remaining biases, the risk of bias was assessed using the Cochrane Risk of Bias Assessment Tool [37]. The assessment of the different biases is summarized in **Figures 2** and **3**.

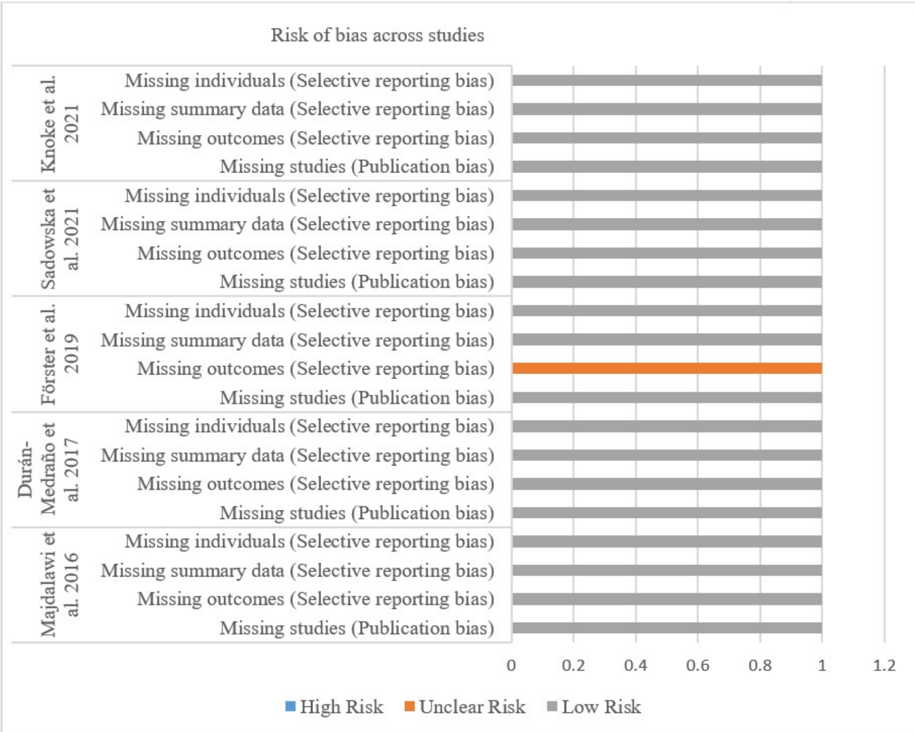

Figure 2. Risk of bias assessment of studies included in the systematic review using the Cochrane tool.

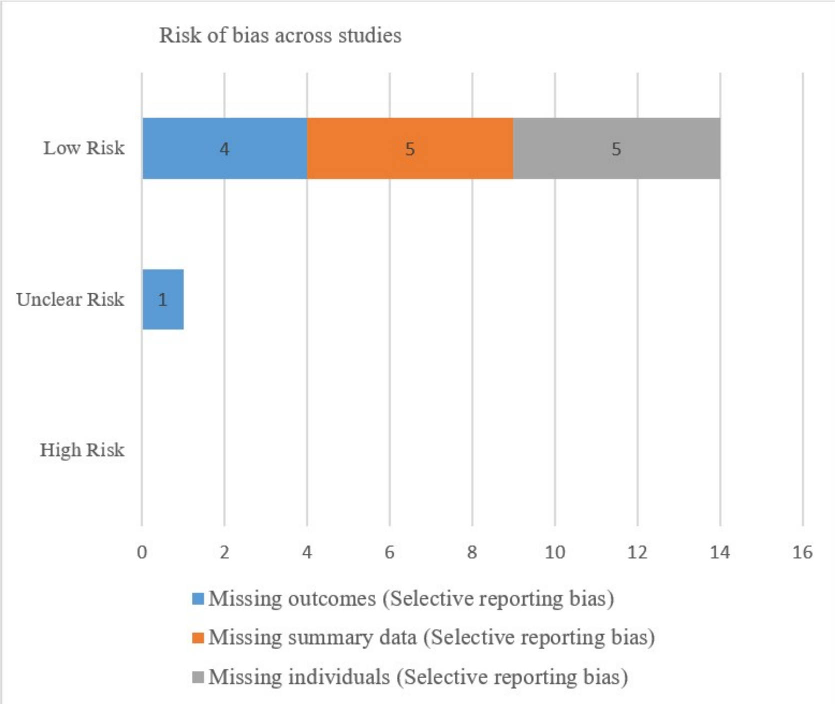

Figure 3. Summary of the level of risk of bias for studies included in the systematic review on the economic valuation of forest degradation. Risk of bias was assessed using the Cochrane risk of bias assessment tool.

3.5. Synthesis of studies

From the different results, it was found that:

Majdalawi et al. 2016: The assessment was done using the productivity method, transportation cost method, market price method, degradation rates, and habitat equivalence analysis method to assess, respectively, land yields (erosion assessment), value of lost recreation areas, timber losses, forest area losses, and reforestation. The sum of these values gave an estimate of forest degradation for 30 years and 100 years from 2014. Thus, degradation was estimated as 596 million Jordanian Dinars ($1 = 0.71 JD) in 2044 and 43,046 million JD in 2114.

Durán-Medraño et al. 2017: The evaluation used the contingent valuation method and a discrete choice experiment (stated preferences) for each individual based on the externalities of forest loss (here, forest loss, increase in pests and diseases, loss of wildlife, erosion) to express the amount of time they are willing to work to protect the forest and their hourly rate, thus the willingness to pay to protect the forest. An average value was determined (10 days/person for a value of €400). $1 = €0.84 in 2017.

Förster et al. 2019: This study, which was a systematic review, assessed, among other things, the conversion of rainforest to grassland or arable land and thus the loss of forest. Most studies apply a combination of valuation methods. The use of replacement costs as a means of valuing ESs is a common approach, followed by choice experiments. In tropical regions, willingness-to-pay and market price methods are given priority. To compare values, the study used the Consumer Price Index and Purchasing Power Parity with 2014 as the baseline year. However, the study did not give a summary mean or median value.

Sadowska et al. 2021: Based on data from previous studies and official national statistics of the country concerned, this study determined the following quantities: the value of forest lost to fire through an index of the value of costs incurred to establish and maintain 1 ha of stand, the stocking level of stands (i.e., the quotient of the actual volume of stands of trees at the first age of felling and the volume potentially achievable by this stand), the area of the burned stand, and the current official selling price of 1 m^3 of wood (for the country concerned). Economic values were calculated for several years. The highest value was recorded in 2015 (6.6 million Zloty), and the lowest in 2017 (1.3 million Zloty). 2018 saw an upward trend with 4.8 million Zloty ($1 = 3.93 Zloty).

Knoke et al. 2021: This was an assessment of economic losses related to climate change through natural disturbances. The sensitivity of economic losses was obtained by assessing changes in expected land value in consideration of the standing timber volume and worst-case values for economic return. The Monte-Carlo simulation method (MCSM) was used. MSMC is a common method for quantifying uncertainties based on randomized experiments to estimate ranges and possible distributions of, for example, future ecological or financial data. To calculate the expected land values, a finite but very long-time horizon (1000 years) was defined. Over this period, damages caused by natural disturbances as well as stochastic events were simulated. To obtain the economic returns, a simulation of the net revenue streams over the 1000 years for each of 20,000 Monte-Carlo iterations was performed. Then, these revenues were discounted and their sum calculated per iteration. To approximate the expected value for the economic criteria, the arithmetic mean of all 20,000 iterations was used. Sets of these simulations (each with 20,000 iterations) for a range of possible rotation periods, T = 30, 40, 50, 60, 70, 80, 90, 100, and 110 years, respectively, were used to find the optimal rotation period. The optimal rotation was identified as the one that maximized the average land expectancy over all iterations. The maximum value of the land expectancy was used to derive the possible economic losses due to disturbances. The economic losses induced by disturbances varied considerably, depending on the valuation approach applied: between −€2,611 and −€34,416 (in 2021; $1 = €0.88). After accounting for extreme events and the impact of disturbances on standing timber, losses were 262 to 1218% higher than the damages derived from standard valuation approaches that neglect these aspects.

3.6. Analysis of the strengths and weaknesses of each study's methodology

An analysis of the strengths and weaknesses of the methodology of each study is summarized in **Table 4**.

Table 4. Analysis of the strengths and weaknesses of the methodology of each included study.

Study	Strengths	Weaknesses
Integration of different environmental valuation methods to estimate forest degradation in arid and semi-arid regions (Majdalawi et al. 2016)	1) Each ecosystem service (ES) loss was valued (fertility loss by the productivity method, timber loss by the market price of timber, recreation loss by the transportation price method); 2) Reforestation was estimated by its cost at the baseline period by taking into account the rate of degradation and the discount rate	1) Of all the methods used, none of them made an economic assessment of NTFPs that have significant value; 2) It cannot be assumed that the rate of degradation was constant from year to year; 3) The values found were only an update of values from previous studies taking into account the inflation rate; 4) All the services lost through ecosystem degradation were not evaluated by the methodologies used (water protection, carbon sequestration, loss of wildlife, etc.). In total, the methods used did not allow for the evaluation of environmental losses
Valuation of terrestrial and marine biodiversity losses caused by forest wildfire (Durán-Medraño et al. 2017)	Discrete choice experiment was a stated preference method based on individual preferences	The main weakness was in the quality of the individuals in the sample: students of social sciences who for the most part (66%) were from urban areas. Indeed, the discrete choice experiment made it possible to evaluate the economic value of the environment by estimating, in monetary terms, the gain or loss of well-being of an individual, through his or her declarations, due to an improvement or degradation of the quality and/or quantity of goods and services produced by a natural asset [44]. An individual who is best placed to appreciate a gain or loss of well-being of a natural asset is someone familiar with the asset concerned. Therefore, the amount he is willing to pay is done so with full knowledge of the facts
Incorporating environmental costs of ecosystem service loss in political decision making: a synthesis of monetary values for Germany (Förster et al. 2019) NB: We retained the part relating to the loss of tropical forest	1) Systematic review; 2) Using willingness-to-pay and market price methods to value tropical forest ES; 3) For tropical forests, frequently valued ES included "biodiversity (habitat, species)", "food supply, multiple ES bundles", "material supply" and "physical experience (recreation)". The study provided a minimum range of monetary values (adjusted for inflation and with 2014 as the baseline year) for each service	No mean or median value of overall synthesis for all services
Forest fires and losses caused by fires—an economic approach (Sadowska et al. 2021)	1) Leveraging wildfire statistics published between 2014 and 2018 and the state of the country's forests financial and economic reports; 2) Induction and synthesis method	The monetary valuation focused only on the value of the loss of wood: the other lost functions of the forest were not valued
Economic losses from natural disturbances in Norway spruce forests—a quantification using Monte-Carlo simulations (Knoke et al. 2021)	1) Monte-Carlo simulation method is a common method for quantifying uncertainties based on random experiments to estimate ranges and possible distributions of, for example, future ecological or financial data; 2) Determination of the present value of the forest (value of land + value of timber) on a long-term basis that takes into account disturbances (uncertainties)	This method determined only the value of the land and the wood. The value of a forest is not limited to that

4. Discussion

We included a total of five articles that evaluated the actual economic cost of forest loss. Of these, only one was a systematic review. This result is sufficient evidence of the difficulty of finding systematic reviews in the field of biodiversity conservation as opposed to health science [35,36].

The current study showed that forest degradation assessments were conducted in an indirect manner. The articles assessed the services provided by the forest, including soil fertility, recreation areas, wood supply, wildlife habitat, and carbon sequestration. However, the assessment omitted soil erosion and water quality [1,40]. Similarly, many studies valued the forest as its direct use value (wood and non-timber forest products, recreation and science/education services, etc.), its indirect use value (water and soils, carbon sequestration, etc.), and/or its option value (the possibility of using the forest in the future) [41–43].

Therefore, we conclude that there are many ways to assess the loss of forest resources. This is one of the difficulties of the economic valuation of forests: the choice among methods and the synthesis of their results [45]. We have identified the market price method, the transportation cost method, the mixed methods, the replacement cost method, the habitat equivalence analysis method, and to a lesser extent the mathematical methods and the stated preference method. The market, when it exists, is used to assess the value of a natural asset [47]. The market price method is often more widely used [2], but some natural resources do not have a market value. Non-market valuation methods are then used [48], among them the transport cost method [40,41,44] and the replacement cost method [30,40]. The habitat equivalence analysis method is also used for natural resource valuation [43]. Finally, the stated preference method has been used in recent years to assess the non-market value of natural resources [2,40,43,45–48].

All of this prior work justifies the use of the identified methods to assess forest degradation. Economic valuation aims to meet the monetary expectations of the public to achieve environmental preservation goals [53], and decision making is increasingly based on economic considerations, including cost-benefit analysis [54]. The key factor in achieving desired economic outcomes and the likelihood of sustainable economic benefits for a project is economic analysis [52]. Estimates of the economic costs and benefits of land use options can inform decision making about the multiple benefits that biodiversity and ecosystems provide to human well-being as well as about the economic consequences of ecosystem loss [50,51]. For example, the economic benefits of biodiversity and ecosystem conservation have been shown to exceed the costs of conservation when multiple benefits of ESs are considered [56]. ES valuation is an approach to support decision making that involves the environment (trade-offs between production and environmental conservation) [51].

In summary, in the economic evaluation of forest loss, several parameters are important. First, the valuation must cover all the services lost: direct and indirect values as well as the option value [41–43]. Second, although no single methodology is used to evaluate forest ESs in general [45], the willingness-to-pay method is particularly useful for evaluating the ESs of tropical forests [30]. However, when the willingness-to-pay method is used, it is appropriate to choose individuals who can better appreciate the welfare gain or loss of the natural asset. Indeed, the discrete choice experiment makes it possible to assess the economic value of the environment by estimating, in monetary terms, the gain or loss of well-being of an individual, through his or her statements, due to an improvement or degradation in the quality and/or quantity of goods and services produced from a natural asset [44].

One obvious observation from the included studies is that they made no mention of institutional weakness. Indeed, we note this weakness from the point of view of proactivity and the implementation of existing regulatory frameworks (treaties and laws). Although it is true that there are few ES indicators available to governments [30], the implementation of existing indicators is a problem. For example, Pata et al. [57] point to the need to use renewable energy research and development to improve environmental quality and reduce the ecological footprint. Although the race for alternatives to fossil fuels is very much on, investment in renewable energy research is also lacking. Furthermore, forests are invaded by uncontrolled logging and pierced by road infrastructures.

This study makes a call to stakeholders for the optimal and sustainable governance of forest resources. We wish to name policymakers, nature conservation organizations, experts, researchers, and the direct users of our forests.

5. Conclusion

The aim of this study was to identify the methods that previous studies used to assess forest degradation in economic terms. These studies showed that the economic evaluation of forest degradation was indirect in character and focused on the various ESs that the forest provided (supply services, regulatory and support services, cultural services). The various evaluation methods can be grouped into two categories: market (timber loss) and non-market (individual preferences). It is advisable to use the willingness-to-pay method and the market price method to evaluate tropical forests ESs. However, some methods, despite receiving growing interest in recent years, notably the stated preference method, were less used. These estimates, although economic, are an important challenge to governments and stakeholders for participatory, social, and sustainable governance of forest resources.

This research appears to be one of the few systematic reviews to study the economic valuation of forest degradation. Future studies could either be a little more flexible in their eligibility criteria or identify articles from a longer period than ours.

6. Limitations

The main limitation of this analysis was that it identified and included a very small number of studies. This may have limited the analysis of the data. For example, it was not possible to quantitatively pool the results of the studies. To avoid this limitation, future studies could either be a little more flexible in their eligibility criteria or identify articles from a longer period than ours.

However, this review had some strengths. The third referee of this study was not only an expert in forest economics but also a teacher-researcher in the same field. This gave more credibility, improved our results, and eliminated any potential bias. In addition, we used a rigorous methodology to conduct the different steps of the analysis; thus, our results are both complete and reproducible. The relevance of our results favors their use by governments, forest conservation organizations, researchers, and students

Acknowledgments: The authors would like to thank all those who provided information for this article.

Conflict of interest: The authors declare no conflict of interest.

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