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Review article

Envisioning better forest transitions: A review of recent forest transition scholarship

Heather MacDonald

Great Lakes Forestry Centre, Canadian Forest Service, Natural Resources Canada, Research Scientist, 1219 Queen Street East, Sault Ste. Marie, P6A 2E5, Ontario, Canada

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ABSTRACT

Forest transition theory, as introduced by Alexander Mather, depicts forest recovery patterns often occurring in the wake of agricultural intensification and farmland abandonment. Since the forest transition theory was introduced, multiple pathways have been described in the scholarly literature to explain forest transition phases via varied socio-economic forces. This analysis of a set of 78 country-specific case studies published from 2019 to 2022 confirms social inequity in documented forest transitions; forest transition case studies from 2019 to 2022 were concentrated in highly developed countries. This review also substantiates the impact of agricultural land use changes in recent forest transitions. Four out of five case studies assessing pathways identified an economic development pathway for forest transitions. The effect of state interventions such as introducing incentives for reforestation in forest transitions reviewed was mixed; while almost one-third of forest transitions were attributed to state policies or laws, negative biodiversity impacts from forest plantations were documented. With respect to social justice, nearly a third of case studies included interviews with villagers or similar methodologies to capture social perceptions of forest transitions. Based on this review, governance and social equity forest transition benefits are critical issues for forest transition research.

1. Introduction

Global efforts to slow and reverse deforestation often employ what is known as a forest transition model to illustrate the evolution in forests over time and characterize spatial differences in the world's forests [1]. A "forest transition", as originally defined by Sir Alexander Mather [2], depicts an inflection point, or a window of opportunity [3], whereby some forests recover after a period of forest loss [2]. The notion of a forest transition emerged when Mather observed empirical similarities in the socioeconomic contexts in which forests in North/Latin America, Europe, Asia, and elsewhere stopped shrinking and started expanding [2,4,5].

Forest transition theory attempts to describe socio-economic processes which contribute to forest recovery. Mather [2] observed that fears of forest loss had overshadowed the fact that forest area had recovered in many locations, resulting in increased forest productivity as well as greater reliance on plantation forests. Mather's forest transition curve resembles a U-shaped curve with time as the horizonal axis and forest cover as the vertical axis [2] (Fig. 1). The "forest transition", according to Mather [2] occurred after the point of maximum forest destruction followed by forest expansion. Notably, Mather described the level of forest-area recovery as less than the pre-loss stage, and cautioned against assuming that the destructive phase was necessary. Mather [2] applied a model which posited that resource depletion was followed by amelioration.

E-mail address: heather.macdonald@nrcan-rncan.gc.ca.

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1.1. Drivers of forest transition

Two of the earliest theories advanced to explain such forest transitions were the economic recovery and forest scarcity pathways [6]. Rudel and colleagues posited that the economic recovery pathway was caused by agricultural concentration on more productive (and typically flatter) land. The economic development pathway also included cases whereby greater wealth or rural outmigration caused agricultural land to be abandoned, allowing forests on former fields to rebound naturally. An alternate, but non-exclusive, pathway to forest transition was denoted as the forest scarcity pathway, in which landowners plant trees because of increasing returns from forest goods and services caused by shrinking forests [6].

In response to the pathways put forward by Rudel and colleagues [6], a variety of other pathways have been proposed. Case studies about forest transitions in Asia (which occurred later than forest transitions in Europe and North America) drew explicit attention to the role of the state in effecting forest policies, logging bans and other mechanisms that were linked to forest cover gains. This government-mediated type of forest transition was termed the state forest transition pathway [7]. Analysis of concurrent imports of timber and food indicated that displacement (by importing timber products [5]) and trade-related imported deforestation [8] were also significant drivers of forest transitions in North/Latin America, Europe, and Asia.

1.2. Subsequent applications of forest transition theory

In 2010 and 2011, the United Nations Framework Convention on Climate Change (UNFCCC) negotiations encouraged countries to identify drivers of land use change [9,10]. In 2012, Noriko Hosonuma and co-authors modified the forest transition model to incorporate both forest cover and deforestation rates [11]. According to this modified forest transition curve, all forests may be classified according to forest cover and deforestation trends [8,11]. Pre-transition locations have high levels of forest cover and low deforestation rates, whereas early-transition locations exhibit high levels of deforestation coupled with high to moderate forest canopy [8]. Late transition locations represent those where deforestation has occurred, but where rates of forest loss are slowing, and finally the post-transition phase is characterized by recovering forest canopy area. This application of the forest transition theory broadened the attraction of the forest transition model, enabling categorization of the world's forests according to position on a hypothetical forest transition curve. At the same time, neither this forest transition model nor Mather's original forest transition theory [2] based on "resource extent" assumes that it is inevitable that all locations proceed through deforestation.

1.3. "Better" forest transitions

Forest transition research has illustrated that the socio-economic context of land use change matters in terms of ecological, economic, and social outcomes. Consequences from agroforestry transitions in Europe and central America differ from plantation transitions more prevalent in parts of Europe and Asia [12]. Ecological, carbon sequestration, and biodiversity effects are different depending on the type of transition [12]. This research shows that the *quality* of forest transitions is important, and therefore, it is necessary not only to review forest transition pathways, but also the various effects of forest transitions on carbon, biodiversity, governance, well-being, and other benefits. Of pressing importance is the need to consider the quality of forest transitions in terms of social equity; this is essential because forest transition research illustrates the stark social inequity of forest transitions. Most forest transitions have historically been in the northern hemisphere [13], consistent with criticisms of the forest transition concept as colonial [12].

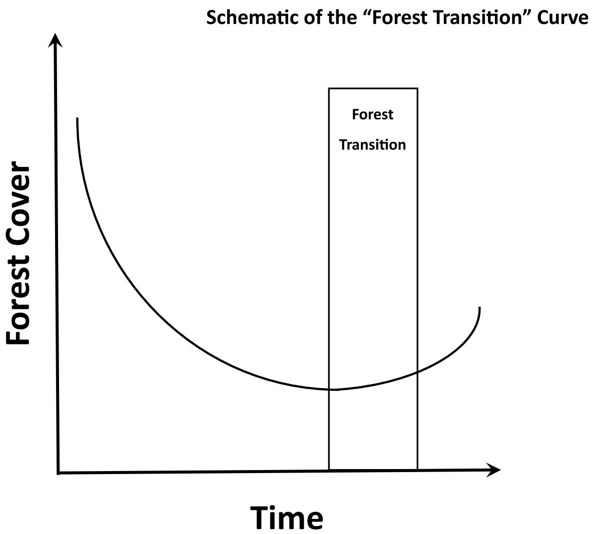

Fig. 1. Forest Transition Curve (adapted from Ref. [2] which labelled the y axis as "resource extent").

1.4. Study objectives

This review of the forest transition literature from 2019 to 2022 considered the prevalence of four different forest transition pathways: a) economic development; b) forest scarcity; c) state; and d) displacement. Transition pathways documented in the literature were summarized overall, as well as by country, continent, and hemisphere. Forest transition impacts were captured regarding carbon sequestration, biodiversity and social equity impacts recorded in forest transition studies published from 2019 to 2022.

2. Methods

2.1. Literature search

This paper summarizes the forest transition literature from October 2019 to October 2022. The time frame was selected to continue a previously published similar environmental scan [14]. Consistent with the methodology in Ref. [14], the search was completed using six databases: Scopus; Web of Science Core Collection; Environment Complete; Business Source Premier; BIOSIS; and Material Science and Engineering. Scholarly and peer reviewed journal articles were retrieved concerning "forest transition". In addition to journal articles, dissertations were also included in return results.

2.2. Coding forest transition publications

Each forest transition study was reviewed to distinguish country-specific case studies from less localized research studies encompassing multiple countries. Each case study (country-specific study) was coded for country-level Human Development Index (HDI), a measure of quality of life [15]. Periods of forest loss and subsequent forest gain were captured from each article's results section; specific indicators recorded included the number of years over which forest canopy change was analysed. Each case study was assessed for evidence for different forest transition "pathways" (Table 1), including the economic development, forest scarcity [6], state [7], and displacement [5] pathways (S1 – coding manual). Pathways were not mutually exclusive; case studies might be coded positively for multiple pathways.

Indicators of the economic development pathway included agricultural intensification (for example, through more advanced fertilizers), decline in populations dependent on agriculture, or rural outmigration. Agricultural intensification was sometimes indicated by agricultural land use on flat, more productive fields, with forests regrowing on higher elevation or sloped elevation sites. Under the economic pathway, rural outmigration or local population decline were recorded, as well as growth in non-agricultural incomes, road development leading to a rural outmigration, or greater reliance on income remittances from family members living overseas.

Specific government policies and stewardship initiatives were recorded where case studies noted these policies or initiatives anywhere in the article. The type of forest, whether consisting of native trees or introduced trees species (also referred to as plantations or "exotics"), was also recorded for forest transition case studies.

Forest transition research studies excluded from the case study analysis (for instance, research about multiple countries) were included in the thematic analyses on carbon, biodiversity, and social equity where appropriate.

2.3. Data visualization and statistical analysis

A heat map (a two-dimensional data visualization representing the quantity of case studies using distinct colors) was created in Microsoft Publisher to depict forest transition pathways. A scatterplot was also generated in R [16] of case study country Human Development Index on average number of years over which land cover change was tracked. SAS software, Version 9.4 of the SAS System for Windows was used to calculate Pearson correlation coefficient (r) for Human Development Index and number of years over which land use change was tracked in case studies.

Table 1
Types of forest transition pathways and associated case study indicators.

Pathway	Indicators/Reason for Forest Regrowth
Economic development [9]	• agricultural intensification (e.g., more advanced fertilizers, agricultural land concentration on flat, more productive fields) • decline in populations dependent on agriculture • rural outmigration (e.g., road development leading to a rural outmigration, possible greater reliance on income remittances from family members living overseas) • rising incomes
Forest scarcity [9]	Forests become a scarce commodity due to over harvesting, and communities value forests more as a result
State [10]	State forest policies, governance, legislation, fines, or forest protection (e.g., through protected areas)
Displacement [5]	Imports replace consumption of domestic forest products

3. Results

3.1. Forest transition case studies published from 2019 to 2022

Using the search term “forest transition”, there were 259 articles or dissertation theses published from October 2019 to October 2022. Removing studies that pertained to “forest transition zones”, 128 publications were identified for the initial basis of this review (Fig. 2). There were 78 forest transition case studies (i.e., publications focusing on a particular country) published from October 2019 to October 2022. The greatest percentage of case studies profiled Asia (43.6%), followed by South America (25.6%), Europe (11.5%),

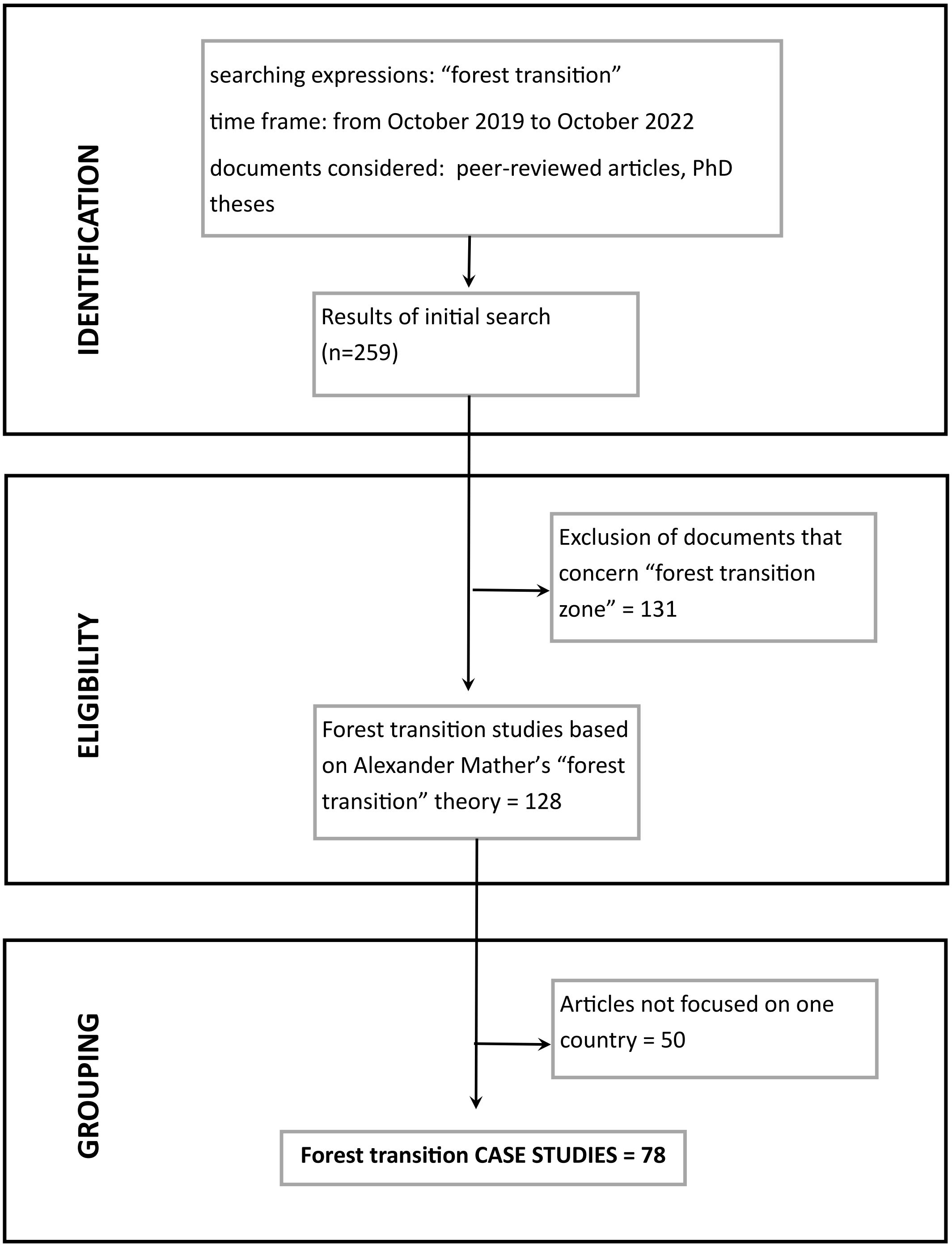

Fig. 2. Review Schematic depicting the total number of articles returned from the search, and number of ineligible/eligible articles.

Africa (10.3%), and North America (9.0%). No qualifying case studies were identified in Australia/New Zealand with "forest transition" as a subject term. By hemisphere, 55 case studies pertained only to forests in the northern hemisphere (70.5%), and 23 were classified as falling fully or partially in the southern hemisphere (29.5%).

By journal subject, the largest group of forest transition case studies was published in economics (43.6%), environmental science (39.5%), and ecology or biology journals (29.5%, Table 2). Fewer than half of case studies focusing on a specific region were published in forestry (26.9%), agriculture (20.5%), or geography journals (10.3%).

Forest transition case studies published from October 2019 to October 2022 were concentrated in highly developed countries, as quantified by the Human Development Index (HDI) [15]. No forest transition case study profiled a low HDI (defined as 0.55 or less) country, compared to 16 countries classified as medium HDI (21.3%), 40 high HDI countries (53.3%) and 19 very high HDI (25.3%; Table 3). In comparison, 16.8% of the world's countries were classified as low HDI in 2021, compared to 23% as medium HDI, 26.2% high HDI and 34% very high HDI (Table 3). Country HDI was positively correlated to the length of time over which land cover was analysed in case studies ($r = 0.41$, Fig. 3).

3.2. *Drivers of forest transitions*

Forest transition case studies published between 2019 and 2022 provide evidence substantiating the economic development pathway (Fig. 4). Of thirty-three case studies assessing pathways, twenty-seven documented identified an economic development pathway for forest transitions (81.8%, Table 4).

Case studies in Zambia and Ecuador confirmed common forest transition "drivers across countries and scales, namely population pressure and the natural condition of land suitability for crop production" [17], p. 1). Zambian deforestation patterns systematically decreased further from settlements, reversing in regions with advanced forest transitions [18]. Population declines occurred with forest recovery in the Mixteca Alta region in Mexico from 1990 to 2018 [19], the Zona da Mata region of Minas Gerais in Brazil from 1986 to 2015 [20], the Tucumán province in Argentina from 1998 to 2017 [21], and Noto and Kunisaki in Japan from 1968 to 2018 [22].

The state pathway, in which government regulations or policies drive forest canopy growth, was identified in nearly one-third of case studies. Specific government programs noted in forest recovery case studies included the Returning Farmland to Forest Program, also called "Sloping Land Conversion Program" or "Grain for Green Program" in China [23,24], and issuance of land titles in Thailand after the 1980s [25]. Even though Brazil case studies documented forest loss, data from 1986 to 2016 highlighted that government laws against deforestation and public policies in the Brazilian Atlantic forest biome contributed to forest recovery when enforced [20]. Three of the state pathway case studies also noted expansion of non-native or exotic trees, rather than natural forests. In Thailand, state and private sector Eucalyptus plantations grew at the same time the population active in agriculture declined [25].

The forest scarcity pathway occurred in most cases alongside the economic development pathway; four out of seven forest scarcity pathway case studies also demonstrated the economic development pathway. Perceived declines in forest products and services in the southern states in the U.S. were described as driving efforts by institutional actors to incentivize tree planting [26]. Displacement of forest products was only identified as a driver in one case study; instead, research illustrated that transitions in the United States and Europe were affected by a major reduction in firewood use with fossil fuel substitution [27,28].

3.3. *Carbon, biodiversity, and social equity outcomes*

Forest transition scholarship globally has enabled evidence-driven conclusions about the quality of forest transitions for carbon, biodiversity, and social equity. Three of six forest transition case studies including measures of biodiversity were in South America, whereas seven of fourteen studies addressing social equity concerned forests located in Asia (Table 5). Overall, most forest transition case studies contained analysis of laws or regulations, including all the Asian case studies and nine out of ten South American case studies.

Given the small number of case studies reporting carbon, biodiversity or social equity impacts, the exploration of these outcomes is in the form of a qualitative interpretation.

Table 2
Number of Country-Specific Publications applying the Forest Transition Theory (October 2019 to October 2022).

Journal Subject	Africa		Asia		Europe		North America		South America		Total	%
Economics	3	37.5%	17	50.0%	5	55.6%	3	42.9%	6	30.0%	**34**	**43.6%**
Environmental Science	5	62.5%	11	32.4%	3	33.3%	4	57.1%	7	35.0%	**30**	**38.5%**
Ecology/Biology	3	37.5%	8	23.5%	3	33.3%	3	42.9%	6	30.0%	**23**	**29.5%**
Forestry	1	12.5%	11	32.4%	2	22.2%	1	14.3%	6	30.0%	**21**	**26.9%**
Agriculture	2	25.0%	10	29.4%	1	11.1%		0.0%	3	15.0%	**16**	**20.5%**
Geography		0.0%	3	8.8%		0.0%	1	14.3%	4	20.0%	**8**	**10.3%**
Total	**8**	100%	**34**	100	**9**	100.0%	**7**	100.0%	**20**	100.0%	**78**	**100.0%**

Journals can be classified into multiple subject areas; as a result, the count of subject categories is greater than the total number of case studies about a specific region.

Table 3
Forest transition case studies by human development index (HDI) category.

HDI Category	Forest Transition Case Studies		Global Distribution	
	Count	% of case studies	Count	% of countries
Low (less than 0.55)	0	0.0%	32	16.8%
Medium (0.55–0.699)	16	21.3%	44	23.0%
High (0.7–0.799)	40	53.3%	50	26.2%
Very high (0.8 or higher)	19	25.3%	65	34.0%
Total[a]	75	100.0%	191	100.0%

[a] Three case studies that applied the forest transition theory but did not feature a forest recovery were excluded from Total.

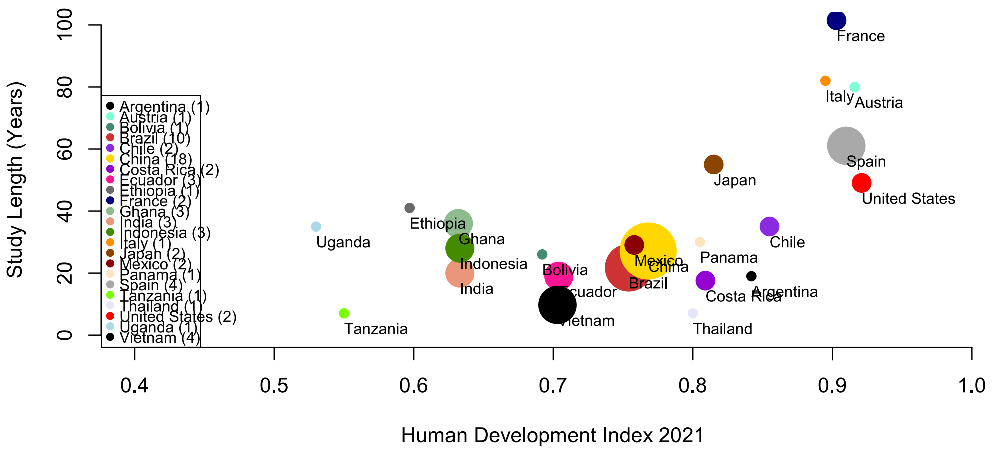

Fig. 3. Scatterplot of Human Development Index by the Average Number of Years Analysed by the Forest Transition Case Study. The size of the marker indicates the number of studies for each country. The exact number of case studies by country is provided in the Legend.

3.3.1. Carbon

Eight forest transition case studies estimated carbon sequestration-related outcomes. Of these, three case studies in Europe and the United States concluded that in addition to forest area expansion, vegetation thickening contributed to growth in forest carbon sequestration [27–29]. In contrast, modest gains in Brazilian Atlantic forests after the early 2000s were reversed due to re-clearing of regenerated forests [30,31]. Not only did this affect most municipalities in the Brazilian Atlantic Forests, but the loss also equated to one-third of regenerating Brazilian Atlantic forests' potential [30]. In Air Telang Protected Forest, Indonesia, coconut plantation establishment caused the greatest land use change carbon emissions from 1985 to 2020 [32].

3.3.2. Governance

Forest governance, defined as the effect of regulatory structures and/or actors on forests, was documented in most case studies (79.4%). Four articles empirically linked forest gain to policy changes. In Bac Kan, Vietnam, new land entitlements led to forest regrowth on land previously under shifting agriculture [33]. In China, policies encouraging farmers to maximize labor productivity in land use resulted in more select land use, and consequently in reclamation and resurgence of ecological services elsewhere [34]. In Ecuador, the "Plan Bosque" compensated landowners not to deforest the remnant forest patches of the basin, contributing to forest protection [35]. Other examples of policies or programs include the U.S. Conservation Reserve program [27], payments for forest ecosystem services, and forest protection in Vietnam [36], public financial support for commercial forest management in Chile [37], Law 071 of the Rights of Mother Earth in Bolivia [38], and Brazil's Action Plan for the Prevention and Control of Deforestation in the Legal Amazon [39].

However, some policies have had the unfortunate impact of displacing natural forests, either with crops or planted trees [40]. Loss of natural forests was attributed to weak governance for four cases of forest loss. In the U.S., planted forests increased by over 180% from 1968 to 2017, whereas natural forest cover declined by over 10%, a trend linked to the Conservation Reserve Program [26]. In Lam Dung, unclear boundaries between forest and non-forest lands allowed rubber companies to convert degraded forest lands into plantations [33]. In China between 1990 and 2013, tree plantations grew faster than natural forests [24].

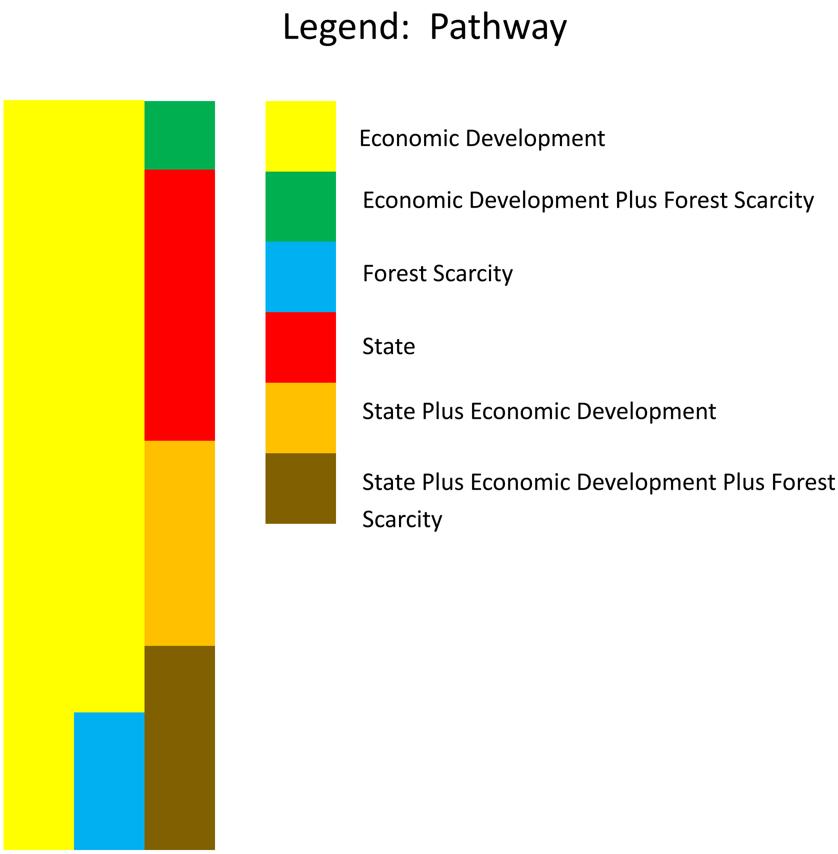

Fig. 4. Heat Map Illustrating the Number of Forest Transition Case Studies by Pathways. Each case study represents a single square.

Table 4
Forest transition pathways – case studies.

Forest Transition Pathway	Southern Hemisphere		Northern Hemisphere		All Case Studies	
	Count	% of case studies	Count	% of case studies	Count	% of case studies
Economic development	3	75.0%	24	82.8%	27	81.8%
State	1	25.0%	9	31.0%	10	30.3%
Forest scarcity	1	25.0%	5	17.2%	6	18.2%
Displacement	0	0.0%	1	3.4%	1	3.0%
Total	**4**	100.0%	**29**	100.0%	**33**	100.0%

Table 5
Percent of Case Studies by Geography for all case studies, and case studies focusing on carbon, biodiversity, governance, and social equity.

	Africa	Asia	Europe	North America	South America	Total
Overall[a]	8	34	9	7	20	78
Carbon	0	3	1	2	2	**8**
Governance[b]	1	12	2	3	9	**27**
Biodiversity	1	1	1	0	3	**6**
Social Equity	3	7	1	1	2	**14**

[a] From Table 3.
[b] Includes case studies with a state forest transition pathway or case studies that document other effects of governance.

3.3.3. Biodiversity

Six of the forest transition case studies measured biodiversity outcomes. Given the challenges measuring biodiversity [12], a variety of innovative data measurement approaches were employed in the forest transition literature (see S1). The case studies reviewed concluded that forest transitions to native tree species housed greater biodiversity than transitions leading to tree plantations. In Peru, forests composed of species such as *Eucalyptus* and oil palm depleted water available downstream and were linked to lower biodiversity

[41]. Biodiversity in forests of South Sumatra, Indonesia, was negatively affected by coconut plantations and other agricultural uses [32]. The long-term implication, where natural forest processes are interrupted by non-native vegetation, is that exotics can outcompete “native species in the early stages” and dominate the succession process [21, p. 1170]. Struggles to re-establish native tree species can result; availability of propagules in Argentina shaped whether native or introduced tree species became established [21].

Secondary forests have a special role to play to temporarily or permanently house biodiversity dislocated due to land use or climate change, as sometimes “small but vital patches” [42], p. 935]. Dry secondary forests in Peru support tree and mammal biodiversity such as insects and insectivorous bats [41]. As well, former tree plantations in southern Ghana regenerated to floristically self-sustaining, structurally complex ecosystems 40 years after abandonment [43].

3.3.4. Social equity

Social equity was considered in results of fourteen forest transition case studies reviewed. Social equity papers spotlighted displacement of people for afforestation (e.g., Spain, [44]; Thailand [25]), instances of economic and political marginalization of Indigenous people [33], as well as instances of Indigenous leadership, such as through Indigenous Comarcas in Panama [45]. Nearly a third of forest transition case studies included interviews or surveys with villagers or other community members (23 of 78).

Forest transition case studies addressed equity of access to the ecological services provided by trees. For instance, a forest transition in southern Ethiopia brought “water availability in rivers, livestock numbers, construction materials and fuelwood availability” [[46], p. 1446]. Other authors have called for explicitly psychological measures of forest benefits, including monitoring well-being benefits from forest transitions. For instance, in response to the Japanese National Forest Plan, which includes forest protection, management, and health functions of forests, subjective well-being has been suggested as a forest transition indicator [47].

3.4. Limitations

This environmental scan suffers from over-representation of natural sciences compared to social sciences in Scopus and Web of Science [48]. To counteract this bias, efforts were made to request research not in these repositories (for instance, based on references contained in the identified articles). Other environmental scans [such as 42] have incorporated more inclusive search terms (such as secondary forest), however, this review was intentionally limited to forest change analysed through the lens of Mather’s forest transition theory. The review is also limited by being restricted to English-language studies, as Scopus and Web of Science are biased towards English-language publications [49]. To compensate for this weakness, a subsequent search was completed in Google Scholar, and one study accessed was an English-language abstract of a non-English publication. Nevertheless, this scan is inclusive primarily of English language articles.

4. Conclusions and discussion

The scholarly literature continues to add rich layers of information to fill in forest transition timelines, guided by Mather’s theory. Of forest transition case studies published from 2019 to 2022, 81.8% were consistent with the “economic development pathway” in which forest cover rebounds as agricultural land use declines, either because of agricultural intensification on productive, low-elevation sites, or because of rural outmigration or income diversification [6]. The forest scarcity pathway was less common and tended to accompany the economic development pathway; such non-exclusivity is consistent with the published literature [5,9].

Forest transitions published from 2019 to 2022 were concentrated in highly developed countries as defined by the Human Development Index. Criticisms of euro-centric bias related to the forest transition are warranted; even so, case studies in the southern hemisphere underscore that a forest transition research frame is helpful to researchers exploring how to balance objectives of ecological conservation with poverty reduction and social justice.

Forest transition theory describes a transformational process of initial deforestation and later forest regrowth. But the forest transition literature is alive with considered case studies that do not mimic mistakes of the global north. For instance, locations with precious, relatively unmined forests have applied forest transition theory to propose side-stepping replacement of biodiverse natural forests with secondary forests for timber production [50,51].

The socio-economic context so important in forest transition research provides vital information and a theory of change by which to facilitate better forest transitions. The implication of this recent body of forest transition research is that the *quality* of forest transitions matters. A global literature characterizes the nature of various forest transitions through attention to carbon, biodiversity, and social equity outcomes. A focus on carbon sequestration has encouraged some countries to look to secondary forests as a clearly defined component of nationally determined contributions. By delving deeper into forest transition benefits, this scholarship has challenged initiatives such as UNFCCC-NDC-REDD+, the Convention on Biodiversity-Aichi biodiversity targets, and the Bonn Challenge, to emphasize naturally regrowing secondary forests [41]. This, like the studies included in this review, demonstrates how the forest transition scholarship has helped direct attention to multiple complex phenomena implicated throughout forest change, specifically by considering forest change against other values such as climate change mitigation, biodiversity, and social justice.

Data availability

The dataset used for this analysis is freely available at the Open Science Framework, DOI 10.17605/OSF·IO/HU27Y, https://osf.io/hu27y/, [52].

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CRediT authorship contribution statement

Heather MacDonald: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e20429.

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