Ecosystem services of ‘Trees Outside Forests (TOF)’ and their contribution to the contemporary sustainability agenda: a systematic review

Colin Scott Peros , Rajarshi Dasgupta , Ronald C Estoque and Mrittika Basu

1 Integrated Sustainability Centre (ISC), Institute for Global Environmental Strategies, Japan
2 Center for Biodiversity and Climate Change, Forestry and Forest Products Research Institute, Tsukuba, Japan
3 Laboratory of Rural Planning, Graduate School of Global Environmental Studies, Kyoto University, Kyoto, Japan

E-mail: dasgupta@iges.or.jp

Abstract
Trees Outside Forests (TOF) were recognized in the United Nations Food and Agricultural Organization’s 2000 Global Forest Resource Assessment as an essential component of sustainable development. Today, however, TOF remain an undervalued resource, with no comprehensive review of the wide spectrum of ecosystem services that are provided by TOF nor of the diversity of tree species that comprises TOF globally. Thus, a global analysis of TOF is vital to quantify their contribution to sustainable development and international climate initiatives. We reviewed the scientific literature to (1) classify and compile a repository of information on TOF resources, including the types of ecosystem services provided by TOF, geographic distribution, land-use type, and spatial pattern; and (2) document the diversity of tree species that comprises TOF globally. After screening the literature, 203 species of TOF were investigated across 20 countries in the 28 articles that we analyzed; another 15 articles across 57 countries did not include taxonomic information. Our results showed that the global distribution of TOF studies was biased toward Europe, revealing data deficiencies across the Global South, despite its contribution to biodiversity and ecosystem services. We also observed a bias in ecosystem service type toward regulating and supporting services, with studies lacking in cultural and provisioning services provided by TOF. Furthermore, studies conducted in urban areas were also lacking. To realize the full potential of TOF for sustainable development and climate initiatives, we conclude that a more holistic understanding of their ecosystem services must be established under national and intergovernmental reporting mechanisms.

1. Introduction

Trees, especially forested trees, are central to international climate initiatives (Köhler et al 2009, Krug 2018, Turner-Skoff and Cavender 2019, Silva Junior et al 2021, UNFCCC 2021), providing ecosystem services necessary to sustain both humans and wildlife (Lindemayer 2009, Gibson et al 2011, Pan et al 2011, Thurner et al 2014, Pugh et al 2019). However, not all trees are found in forests (Guo et al 2014, Schnell et al 2015a, 2015b, Zomer et al 2009, 2014, 2016). Trees Outside Forests (TOF) constitute tree formations ranging from scattered trees to systematically managed trees in agroforestry systems and from woody patches within urban systems to trees along rivers, streams and canals. The United Nations (UN) Food and Agricultural Organization’s (FAO) Global Forest Resource Assessment (FRA) of 2000 was one of the first reports to define and recognize TOF (Pain-Orcet and Bellefontaine 2004). The FAO defines TOF as all trees on land that do not meet the definitions of forests and other wooded lands due to size and/or land use. Here, forests are defined by the FAO as land no less than 0.5 hectares with a tree canopy cover of more than 10%, further stipulating that the trees should be able to reach a minimum of 5 meters in height at maturity in situ. ‘Other wooded land’ (OWL) is defined by similar
parameters at smaller scales. For example, all of the following describe OWL: (1) crown cover of 5%–10% of trees that are able to reach 5 meters in height at maturity in situ; or (2) crown cover of more than 10% of trees not able to reach 5 meters in height at maturity in situ; or (3) shrub or bush cover of more than 10%. Moreover, the FAO forest and other wooded lands definitions notably exclude land that is predominately under agricultural or urban land use. Accordingly, in 2005, FAO added a category of ‘Other Land with Tree Cover’ (OLwTC) to the FRA to account for forests that meet the FAO forest definitions but were situated outside of natural ecosystems—predominately in agricultural or urban settings (FAO 2006). Thus, according to the FAO definition, TOF may include trees on agricultural land, urban land, and barren land, as well as trees on land that fulfills the requirements of ‘wooded land’ except for size (Bellefontaine et al. 2002).

The FAO categorizes TOF by the spatial pattern of trees and the land use where the trees are found. Spatial patterns include isolated/scattered trees with minimal inter-tree interactions, trees in lines, such as along rivers or roads, and groups of trees (Kleinn 2000, de Foresta et al. 2013, Schnell et al. 2015a, 2015b). Spatial patterns of trees are important to recognize community interactions and biological processes (Hardy and Sonké 2004, Getzin et al. 2008). The FAO categorizes TOF by land use as follows: lands predominately under agricultural use, lands predominately under urban use, and lands not predominately under agricultural nor urban use (Kleinn 2000, de Foresta et al. 2013, Schnell et al. 2015a, 2015b). These categories address prominent land-use changes of the Anthropocene, which has been defined by human-induced degradation of ecosystems, depletions of resources, and disruption of global processes (Steffen et al. 2011, Barnosky et al. 2012). Nearly 6 million km² of land globally is estimated to be transformed into urban areas in the next decade (Seto et al. 2012). Furthermore, global food demand is projected to increase by 70%–100% by 2050 (Godfray et al. 2010, Tilman et al. 2011). These production gains are predicted to occur at the cost of biodiversity (Laurance et al. 2014, Zabel et al. 2019). However, global tree cover and biomass on agricultural lands have increased over the past decade (Zomer et al. 2016, Song et al. 2018). In fact, the first global assessment of TOF on agricultural lands found that 46% of lands had more than 10% tree cover (Zomer et al. 2009); and tree cover on agricultural lands continues to increase (Zomer et al. 2014). The status of trees on lands predominately under agricultural and urban use may be an important indicator of planetary health as Earth’s biospheres continue to shift (Steffen et al. 2011, Barnosky et al. 2012, Laurance et al. 2014, Zabel et al. 2019).

Although conservation and restoration of forests may hold the key to many pressing environmental problems, including poverty reduction and mitigation of global climate change (Zomer et al. 2008, Griscom et al. 2017), the scope of enhancing formal forests is limited. Forests globally are more susceptible to climate change than previously estimated (Allen et al. 2015). Even worse, the mortality rates of tropical forests are projected to increase (McDowell et al. 2018). Abiotic (fire, drought, wind, snow and ice) and biotic (insects and pathogens) disturbance agents further threaten the future of forests (Seidl et al. 2017). Studies show that forest loss is prevalent even within protected areas (albeit at slower rates than non-protected forests), which account for ~5% of global tree cover (Hellwig et al. 2019, Wade et al. 2020). Protected areas are under growing threats from anthropogenic activities, including, but not limited to, agriculture, logging, development, and bushmeat hunting (Geldmann et al. 2014, Lindsey et al. 2014, Jones et al. 2018, Peros et al. 2021). Despite having conservation as the primary objective of management, an estimated 25.5 million hectares of forests within protected areas were lost globally (~4% of forested areas) between 2001 and 2018 (Wade et al. 2020). At the 10th Conference of Parties (COP 10) to the Convention on Biological Diversity, 20 Aichi Targets were adopted to achieve conservation and sustainable use of biodiversity. Aichi Target 11 called, specifically, for conservation through ‘connected systems of protected areas and other effective area-based conservation measures,’ highlighting the importance of trees beyond formal forests and protected areas (i.e., TOF).

It is well established that TOF can play a pivotal role in carbon mitigation (Niles et al. 2002). At a national level, TOF can also contribute significantly to biomass stocks (Guo et al. 2014, Schnell et al. 2015a, 2015b). One comparative study of TOF in 11 countries across three continents found that 10% of the national above-ground tree biomass was found outside of formal forests (Schnell et al. 2015a, 2015b). In Bangladesh, for instance, TOF accounted for over 75% of tree biomass (Schnell et al. 2015a, 2015b). Furthermore, total TOF biomass globally has been increasing over time. Over the last three decades in China, total TOF biomass has increased (Guo et al. 2014). Important for global wood industries (Warman 2014, Ghosh and Sinha 2018), TOF in some cases provide the only wood resources to local populations (Ahmed 2008, Krishnankutty et al. 2008). In developing regions, TOF supply 67% of fuelwood consumption (Smeets and Faaij 2007). TOF also contribute to the livelihood of rural households, playing a major role in supplying fuelwood, fodder, and fruits (Regmi and Garforth 2010). Thus, TOF should be a focus of scientific study, especially for forest-poor nations such as the countries in central and western Asia (Thomas et al. 2021).

Similarly, urban trees provide a number of ecosystem services and functions (Dobbs et al. 2011, McPherson et al. 2011, Roy et al. 2012, Silvera Seamans 2013, Livesley et al. 2016). Benefits of urban trees include reducing pollution, removing greenhouse gases (Nowak et al. 2006), improving stormwater management (Xiao and McPherson 2003, Armson et al. 2013), and mitigating the urban heat island effect at local scales (Oke et al. 1989,
Bowler et al 2010, Loughner et al 2012, Norton et al 2015, Estoque et al 2017). Trees in urban areas may also bridge the growing divide between humans and nature, increase bioaffinity and enrich urban life altogether (Turner et al 2004, Miller 2005, McKinney 2006, Wolf et al 2020, Dasgupta et al 2022). In addition to the direct benefits to humans, trees in developed areas also enhance landscape connectivity for wildlife (Zhang et al 2019).

Although TOF provide services similar to those provided by formal forests and forests in protected areas (Skole et al 2021), conservation policies over prioritize the protection of formal forests and protected areas (Ravindranath et al 2014). Not all countries consider TOF in conventional forest assessments. Recently, a range of international initiatives however required the inclusion of TOF to meet adequate levels of reporting, including the Convention on Biological Diversity, the Global Forest Resource Assessment, and the United Nations Framework Convention on Climate Change (UNFCCC). For example, the UNFCCC requires information on TOF woody biomass for greenhouse gas reporting (Eggleston et al 2006).

In this paper, we reviewed the scientific literature to explore the current understanding of TOF. Our aim was to evaluate the contribution of TOF to the contemporary sustainability agenda by classifying and compiling information on TOF, including the types of ecosystem services provided by TOF, geographic distribution, land-use type, spatial pattern, and the species that comprise TOF globally. Based on this review, we provide recommendations for future research by identifying knowledge and policy gaps in the current disclosures.

2. Methods

2.1. Database and review protocol
To explore the diverse ecosystem services of TOF, we adopted the Preferred reporting items for systematic review and meta-analysis protocol (PRISMA) (Page et al 2021). We searched the Scopus literature database (https://www.scopus.com/) on July 26, 2021 using the Boolean search string: TITLE-ABS-KEY (tree AND outside AND forests) AND TITLE-ABS-KEY (ecosystem AND services). Scopus, among the largest academic database, presents an extensive repository of scientific literature, including forestry, environment, social sciences, arts and humanities (Falagas et al 2008, Basu and Dasgupta 2021). The search was not restricted by publication date nor language. However, only articles that provided full text in English were considered for analyses. The search yielded 100 articles (see appendix 1 for a full list of articles). Eight articles that did not provide full text in English were excluded. Thereafter, we manually screened the resulting article abstracts to include only primary literature that explicitly evaluated ecosystem services in TOF and included access to taxonomic information of tree(s) under investigation (hereafter species studies), which the author(s) referred to as 'TOF', did not explicitly refer to as forests, and/or matched the definition of the term described in the Global Forest Resources Assessments of the FAO (de Foresta et al 2013). We also included studies that investigated ecosystem services in TOF for which taxonomic information of tree(s) under investigation was not accessible (hereafter non-species studies). Large-scale remote sensing investigations and studies evaluating regulating ecosystem services, for example, often did not report on taxonomic information and were thus included in non-species studies. We retrieved the full text of the articles meeting these criteria and manually screened out the articles that did not provide evidence on the same criteria in full-text. After screening abstracts and full-texts, 57 articles were excluded, leaving 43 relevant articles (figure 1).

2.2. Meta-analysis
We extracted the following information from the relevant species studies that we identified: (1) type of ecosystem services provided by TOF, (2) location of investigation, (3) land-use type and spatial pattern, and (4) species of trees investigated. Using the Millennium Ecosystem Assessment (Reid et al 2005), ecosystem services were categorized as follows: provisioning, regulating, cultural, and supporting. Studies that evaluated species richness and/or biodiversity of TOF were categorized under supporting services (Schwartz et al 2006, Balvanera et al 2006, Lohbeck et al 2016, Soliveres et al 2016). We categorized land-use type in accordance with FAO (Kleinn 2000, de Foresta et al 2013, Schnell et al 2015a, 2015b) as follows: agricultural areas, urban or developed areas, non-agricultural/ non-urban areas, and other/not specified. Similarly, we categorized spatial patterns in accordance with FAO (Kleinn 2000, de Foresta et al 2013, Schnell et al 2015a, 2015b) as follows: scattered trees, trees in line, trees in strands, and other/not specified. However, the spatial pattern of TOF resources was seldom reported. The same information was compiled for relevant non-species studies excluding species of trees investigated. For meta-analysis of the extracted information from the relevant species studies, we counted each evaluation of ecosystem service type from each tree species collected from each country, associated with each land-use type and with each spatial pattern, in each article as a case. For meta-analysis of the extracted information from the relevant non-species studies, we counted each evaluation of ecosystem service type from each country, associated with each land-use type and with each spatial pattern, in each article as a case. The results presented in the result section derive from cross-tabulation of the attributes of all cases.
2.3. Data analysis

All figures were constructed in R (v.3.6.2) (R Core Team 2014). Only data on taxonomic information at the species level were included in phylogenetic analyses. We used the package ‘rotl’ (v.3.0.11) (Michonneau et al. 2016) to match taxonomic names to the Open Tree of Life (Hinchliff et al. 2015). The Open Tree of Life Taxonomy synthesizes taxonomic information and assigns each taxon a unique numeric identifier or Open Tree Taxonomy identification tags (OTT ID). Using these OTT ID’s of species that were compiled in our analyses as search properties, a phylogenetic tree from previous studies that included all of these unique taxonomic tags could not be identified. Therefore, we extracted an induced tree from the Open Tree of Life corresponding to the taxonomic tags of the TOF species that were compiled. The resulting phylogeny contained 203 tips and was rooted without branch lengths. We used the package ‘ape’ (v.5.6) to compute arbitrary branch lengths for the resulting tree (Paradis and Schliep 2019) and the package ‘phytools’ (v.1.0-1) to visualize comparative analyses (Revell 2012). The same process was used to construct phylogenetic trees at the genera and familiae levels.

3. Results

We classified and compiled all four types of ecosystem services as describe in the Millennium Ecosystem Assessment from the relevant studies. Studies evaluating regulating services commonly focused on carbon-related benefits, quantifying carbon stock and sequestration of TOF resources; supporting services were often described in the context of biodiversity, detailing species abundance and distribution; while provisioning services commonly focused on TOF as timber and/or food resources, especially in rural areas; and cultural services exclusively focused on the monetary value of trees in urban settings in the United States, with the exception of one study that focused on recreational benefits of trees in Israel.

After screening all irrelevant studies from the 100 Scopus search results, our analyses included 28 species studies and 15 non-species studies, with 45.2% of the total cases (256/567 cases) in Europe; 22.6% (128/567 cases) in Asia; 17.6% (100/567 cases) in Africa; 5.6% (32/567 cases in Central America; 5.1% (29/567 cases) in North America; 3.4% (19/567 cases) in South America; and 0.5% (3/567 cases) in Oceania (figure 2).

For the 28 species studies, 203 species of trees were referenced in 20 countries (figure 2(a)), totaling 439 cases (see appendix 2 for a full list of the specific cases and the type(s) of ecosystem service evaluated in each case). Several species were reported in more than one article; a few studies were conducted in numerous countries and across different land-use types; and a number of studies evaluated multiple types of ecosystem services, namely regulating and supporting services. Accordingly, 52.2% of the cases (229/439 cases) evaluated supporting services; 40.3% (177/439 cases) evaluated regulating services; 6.4% evaluated provisioning services (28/439 cases), and 1.1% (5/439 cases) evaluated cultural services (figure 3(a)). Regarding land-use type, agricultural areas were most frequently reported (48.3%; 212/439 cases); non-agricultural, non-urban areas accounted for 13.4% (59/439 cases); and urban areas for 10.9% (48/439 cases). Land-use type was not specified in one study,
accounting for 27.3% (120/439) of the cases (figure 3(b)). Sweet cherry (*Prunus avium*) was the TOF species cited the most times with 8 cases (figure 4; and see appendix 3 for a full list of the number of cases and type(s) of ecosystem services for each tree species). As such, *Prunus* and *Rosaceae* were the most cited TOF genus and family with 29 and 48 cases, respectively (figures S1 and S2; and see appendix 4 and 5 for a full list of the number of cases and type(s) of ecosystem services for each tree genera and familiae, respectively).

For the 15 non-species studies, ecosystem services associated with TOF were evaluated across 57 countries (figure 2(b)), totaling 129 cases (see appendix 6 for a full list of the non-species cases and the type(s) of ecosystem service evaluated in each case). A majority of the cases evaluated regulating services (86.8%; 112/129 cases), followed by supporting services (9.3%; 12/129), cultural services (3.1%; 4/129 cases), and provisioning services (0.8%; 1/129 cases) (figure 3(c)). Regarding land-use type, agricultural areas were most frequently reported (45.7%; 59/129 cases); non-agricultural, non-urban areas accounted for 45.0% (58/129 cases); and urban areas for 8.5% (11/129 cases). Land-use type was not specified in one global study, accounting for 0.8% (1/129) of the cases (figure 3(d)).

4. Discussion

4.1. Learning from the results

Despite recent interests, TOF remain an overlooked and undervalued resource that are seldom accounted for from an academic perspective. To the best of our knowledge, there is no comprehensive review of the wide
spectrum of ecosystem services that are provided by TOF nor of the diversity of tree species that comprise TOF globally. Understanding ecosystem services can demonstrate the importance of TOF to help achieve the SDGs and climate targets. At the same time, recognizing biodiversity of TOF can also support conservation efforts. Combined, this information can inform policy decisions and quantify the contribution of TOF to the contemporary sustainability agenda.

Ecosystem services provided by TOF were investigated in 66 counties (figure 2). However, we found that the global distribution of studies was biased towards Europe. Our analyses clearly revealed studies lacking across the Global South, despite its overwhelming contribution to global biodiversity and ecosystem services (Girardello et al 2019), as well as the prevalence of forest and land degradation (Barlow et al 2018, McDowell et al 2018). This geographical bias was also observed in the species of TOF studied, with nearly a third of the cases for tree species that are native to temperate regions or the Northern Hemisphere, including Rosaceae, Betulaceae, and Pinaceae. These geographical biases may have exacerbated biases in the types of ecosystem services that were evaluated.

We also observed a bias in the types of ecosystem service that were evaluated, with a majority of studies evaluating regulating and supporting services (figures 3(a) and (c)). Studies that evaluated regulating services typically focused on carbon sequestration; while studies that evaluated supporting services typically focused on biodiversity. Our analyses clearly revealed studies lacking evaluations of cultural and provisioning ecosystem services provided by TOF. Studies that focus on cultural ecosystem services provided by TOF can help quantify factors that determine connectedness to nature and place attachment (Gosling and Williams 2010, Soga and Gaston 2016, Ko and Son 2018, Vaz et al 2018, Schilling et al 2020, Basu et al 2021); while studies that focus on provisioning ecosystem services can help highlight an underappreciated resource for food and renewable energy (biomass). Accordingly, improving management and monitoring of TOF may be an under-developed strategy to address SDG 2—Zero Hunger (Blesh et al 2019) and SDG 7—Affordable and Clean Energy (Warman 2014).

Finally, there was a bias in the relevant articles regarding the land-use type associated with TOF, with a majority of studies conducted in agricultural areas (figures 3(b) and (d)). Food production gains are predicted to occur at the costs of biodiversity (Laurance et al 2014, Zabel et al 2019). Thus, the investigation of TOF on agricultural lands are important to link global food security and biodiversity conservation (Tscharntke et al 2012). However, our analyses revealed studies lacking specifically in urban areas, where the portion of people living in urban areas is projected to increase from 55% to 68% by the 2050, including over 1.9 billion people living in developing countries (United Nations 2018). Thus, TOF in urban areas may play an undervalued role in providing ecosystem services to a majority of the human population (Sutton and Anderson 2016, Mexia et al 2018, Valente et al 2020). Altogether, TOF may be an important resource of other effective area-based conservation measures (OECD) and should be prioritized to achieve both sustainable development and sustainable use of biodiversity.
4.2. Challenges in TOF monitoring and ways forward

Despite the articulation of TOF by the FAO as early as the 1990s, the definition and application of TOF vary by country. For example, in India, TOF are defined as trees growing outside recorded forest areas irrespective of patch size (Forest Survey of India 2019). A study in Italy defined TOF units in accordance with the Italian national forest inventory (Marchetti et al 2018). Similarly, a study in China defined TOF based on data collected via China’s forest inventory (Guo et al 2014). In most cases, TOF are defined vis-à-vis forests. Therefore, one can only identify, locate, quantify, and monitor TOF if the forest boundary has been defined and delineated. But we know that forest definition varies across countries and geographic regions; and, as previous work has highlighted, the UN’s definition of forests can be problematic and have major implications on measuring greenhouse gas emissions and monitoring forest degradation (Sasaki and Putz 2009, Putz and Redford 2010, Estoque et al 2021).

Figure 4. Phylogeny of TOF species induced from the Open Tree of Life (Hinchliff et al 2015), in which the bars at the tips represent the total number of cases by type of ecosystem service evaluated in relevant studies. Each tip corresponds to a unique tree species identified in our meta-analyses. See appendix 3 full list of the number of cases and type(s) of ecosystem services for each tree species.

References to TOF were inconsistent in the articles resulting from the Scopus search string used in our study. While certain studies explicitly referenced TOF (albeit the differing definitions of TOF applied as discussed above) (Guo et al 2014, Marchetti et al 2018, Chen and Wang 2020, Bhandari et al 2021), references to non-forested trees in other studies commonly included, but were not limited to, agroforests and urban trees.
The framework should be established.

To document TOF, a number of studies have applied multiple data sources such as satellite/hyperspectral data, LiDAR, and intelligent image segmentation and object-based classification techniques. These data sources are effective to identify tree species or tree species in urban areas. Moreover, urban forests are an important resource for ecosystem services. Trees outside forests are also contributing to landscape planning and integrating various ecosystem services of TOF and allows for a more global perspective to integrate TOF into the international framework policy.

Despite providing a plethora of important ecosystem services, TOF are still undervalued resources and are underrepresented in national and regional level sustainability goals and targets. In this paper, we provided a syntheses of the TOF literature based on a systematic review of scientific literature. As stricter conservation policies and regulations have restricted the exploitation of resources from forests, TOF has emerged as an important resource, especially for countries with low forest cover. In Bangladesh, a country scale study on TOF, for example, mapped 31% and 53% more TOF than existing estimates of TOF and forest, respectively (Thomas et al. 2021). Enabling legislation can help realize the full potential of TOF in India (Ghosh and Sinha 2018, 2019), where TOF is the main source of wood (Pandey 2008). Altogether, a more wholistic accounting of TOF resources can highlight the role of emerging countries in realizing the full potential of TOF in the contemporary sustainability agenda. Combined with additional field data, TOF inventories can have major implications on implementing carbon accrediting schemes such as REDD+ and measuring progress for the SDGs.

5. Conclusion

Despite providing a plethora of important ecosystem services, TOF are still undervalued resources and are seldom included in national inventories and international reporting frameworks. At the same time, the scope of improving formal forests remains limited in many countries, exacerbating the need to integrate TOF and its ecosystem services in national and regional level sustainability goals and targets. In this paper, we provided a synthesis of the TOF literature based on a systematic review of scientific literature. Despite data deficiencies across the Global South, we identified 203 species of TOF and provided a rich repository of information, including ecosystem services provided by TOF, geographic distribution, land-use type and spatial pattern. These findings demonstrate that TOF may be an important resource of OECM. As such, TOF should be further integrated into efforts to achieve conservation and sustainable use of biodiversity. We further observed that TOF are fairly established for their impeccable regulating and supporting services, while still undervalued for provisioning and cultural services. In conclusion, we argue that in order to realize the full potential of TOF in the contemporary sustainability agenda, proper national and intergovernmental assessment and reporting framework should be established.

Acknowledgments

This work was supported by the Asia-Pacific Network for Global Change Research (Funder ID: https://doi.org/10.13039/100005536; Award ID: CRRP2018-03MY-Hashimoto). RCE was supported by the Japan Society for the Promotion of Science through its Grants-in-Aid for Scientific Research (KAKENHI) Program (Category C: Number 22K01038). The views expressed in this article are of the authors and do not necessarily reflect the position of the funders and the authors’ respective institutions. The authors also thank the anonymous reviewers for their constructive and insightful comments and suggestions.
Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

ORCID iDs

Rajarsi Dasgupta https://orcid.org/0000-0003-051-5090
Ronald C Estoque https://orcid.org/0000-0001-9681-492X
Mrittika Basu https://orcid.org/0000-0001-6588-9689

References

Ahmed P 2008 Trees outside forests (TOFs): a case study of wood production and consumption in Haryana International Forestry Review 10 165–72
Allen C D, Breshears D D and McDowell N G 2015 On underestimation of global vulnerability to tree mortality and forest die-off from hotter drought in the Anthropocene Ecosphere 61 1–35
Armstrong D, Stringer P and Ennos A R 2013 The effect of street trees and amenity grass on urban surface water runoff in Manchester, UK Urban Forestry & Urban Greening 12 282–6
Balvaniar P, Pfisterer A B, Buchmann N, He J S, Nakashizuka T, Raffaelli D and Schmid B 2006 Quantifying the evidence for biodiversity effects on ecosystem functioning and services Ecology Letters 9 1146–56
Barlow J et al 2018 The future of hyperdiverse tropical ecosystems Nature 559 517–26
Barnosky A D et al 2012 Approaching a state shift in Earth’s biosphere Nature 486 52–8
Basu M and Dasgupta R 2021 Where Do We Stand Now? A Bibliometric Analysis of Water Research in Support of the Sustainable Development Goal 6, December
Basu M, Dasgupta R, Kumar P and Dhyani S 2021 Home gardens moderate the relationship between covid-19–induced stay-at-home orders and mental distress: a case study with urban residents of India Environmental Research Communications 3 105002
Bellefontaine R (ed) 2002 Trees Outside Forests: Towards better Awareness/Ronald Bellefontaine (Rome: International Cooperation Centre on Agrarian Research for Development and Food and Agriculture Organization of the United Nations)
Bhandari S K, Maraseni T, Timilsina Y P and Parajuli R 2021 Species composition, diversity, and carbon stock in trees outside forests in middle hills of Nepal Forest Policy and Economics 125 102402
Blesh J, Hoey L, Jones A D, Friedmann H and Perfecto I 2019 Development pathways toward ‘zero hunger’ World Development 118 1–14
Bowler D E, Bulleyng-Ali L, Knight T M and Pullin A S 2010 Urban greening to cool towns and cities: a systematic review of the empirical evidence Landscape and Urban Planning 97 147–55
Chen B and Wang Y C 2020 Carbon storage in old-growth homestead windbreaks of small islands in Okinawa: toward the sustainable management and conservation Forests 11 1–13
Dasgupta R, Basu M, Hashimoto S, Estoque R C, Kumar P, Johnson B A, Mitra B K and Mitra P 2022 Residents’ place attachment to urban green spaces in Greater Tokyo region: an empirical assessment of dimensionality and influencing socio-demographic factors Urban Forestry and Urban Greening 67 127438
de Foresta H, Somarriba E, Termu A, Boulanger D, Feulhy H and Gauthier M 2013 Towards the Assessment of Trees Outside Forests a Thematic Report Prepared in the Framework of the Global Forest Resource Assessment
 Dobbs C, Escobedo F J and Zipperer W C 2011 A framework for developing urban forest ecosystem services and goods indicators Landscape and Urban Planning 99 196–206
 Estoque R C et al 2021 Remotely sensed tree canopy cover–based indicators for global monitoring of sustainability and environmental initiatives Environ. Res. Lett. 16 044047
 Estoque R C, Murayama Y and Miynt S W 2017 Effects of landscape composition and pattern on land surface temperature: an urban heat island study in the megacities of Southeast Asia Sci. Total Environ. 577 349–59
 Falagas M E, Pitsouni E I, Malietzis G A and Pappas G 2008 Comparison of PubMed, Scopus, Web of Science, and Google Scholar: strengths and weaknesses FASEB J. 22 338–42
 FAO 2006 Global Forest Resources Assessment 2005: Progress Towards Sustainable Forest Management (Rome: Food and Agriculture Organization of the United Nations)
 Forest Survey of India 2019 State of Forest Report. https://fsi.nic.in/forest-report-2019
 Geldmann J, Joppa L N and Burgess N D 2014 Mapping change in human pressure globally on land and within protected areas Conservation Biology: The Journal of the Society for Conservation Biology 28 1604–16
 Getzin S, Wiegand T, Wiegand K and He F 2008 Heterogeneity influences spatial patterns and demographics in forest stands Journal of Ecology 96 807–20
 Ghosh M and Sinha B 2018 Policy analysis for realizing the potential of timber production from trees outside forests (TOF) in India International Forestry Review 20 89–103
 Ghosh M and Sinha B 2019 Institutional imperatives for promoting trees outside forests (TOFs) to enhance timber production in India Small-Scale Forestry 18 57–79
 Gilson L et al 2011 Primary forests are irreplaceable for sustaining tropical biodiversity Nature 478 378–81
 Girardello M, Santangeli A, Mor E, Chapman A, Fattorini S, Naidoo R, Bertolino S and Svenning J C 2019 Global synergies and trade-offs between multiple dimensions of biodiversity and ecosystem services Sci. Rep. 9 1–8
 Godfray H C J, Beddington J R, Crute I R, Haddad L, Lawrence D, Muir J F, Pretty J, Robinson S, Thomas S M and Toulmin C 2010 Food security: the challenge of feeding 9 billion people Science 327 812–8
 Gosling E and Williams K J H 2010 Connectedness to nature, place attachment and conservation behaviour: testing connectedness theory among farmers Journal of Environmental Psychology 30 298–304
 Griscom B W et al 2017 Natural climate solutions Proc. Natl. Acad. Sci. 114 11611650
 Guo Z D, Hu H F, Pan Y D, Birdsley R A and Fang F Y 2014 Increasing biomass carbon stocks in trees outside forests in China over the last three decades Biogesociences 11 4115–22
Hardy O J and Sonke B 2004 Spatial pattern analysis of tree species distribution in a tropical rain forest of Cameroon: assessing the role of limited dispersal and niche differentiation Forest Ecology and Management 197 191–202
Hellwig N, Walz A and Markovic D 2019 Climatic and socioeconomic effects on land cover changes across Europe: does protected area designation matter ? PLoS One 14 e0219374
Hinchliff C E et al 2015 Synthesis of phylogeny and taxonomy into a comprehensive tree of life PNAS 112 12764–12769
Jones R K, Venter O, Fuller R A, Allan J R, Maxwell S L, Negret P J and Watson J E M 2018 One-third of global protected land is under intense human pressure Science 360 788–91
Kanniah K D and Siong H C 2017 Urban forest cover change and sustainability of Malaysian cities Chemical Engineering Transactions 56 673–678
Kleinn C 2000 On large-area inventory and assessment of trees outside forests Unasuya 51 1–10
Ko H and Son Y 2018 Perceptions of cultural ecosystem services in urban green spaces: a case study in Gwacheon, Republic of Korea Ecol. Indic. 91 299–306
Kohl M, Baldauf T, Plugee D and Krug J 2009 Reduced emissions from deforestation and forest degradation (REDD): a climate change mitigation strategy on a critical track Carbon Balance Manage. 4
Kong F and Nakagoshi N 2006 Spatial-temporal gradient analysis of urban green spaces in Jinan, China Landscape and Urban Planning 78 147–164
Krishnakutty C, Thampi K and Chandramannil M 2008 Trees outside forests (TOF): a case study of the wood production—consumption situation in Kerala International Forestry Review - INT FOR REV 10 156–64
Krug J H A 2018 Accounting of GHG emissions and removals from forest management: a long road from Kyoto to Paris Carbon Balance Manage. 13 1–11
Laurance W F, Sayer J and Cassman K G 2014 Agricultural expansion and its impacts on tropical nature Trends in Ecology and Evolution 29 107–16
Lindemayer D B 2009 Forest wildlife management and conservation Ann. N.Y. Acad. Sci. 1162 284–310
Lindsay P A, Nyrende V R, Barnes J I, Becker M S, McBroll R, Tambling C J, Taylor W A, Watson F G and V’Sas-Röfes M 2014 Underperformance of African protected area networks and the case for new conservation models: insights from Zambia PLoS One 9 e94109
Lisnawati A, Lahie A M, Simarangkirting B D A S, Yusuf S and Ruslim Y 2017 Agroforestry system biodiversity of Arabica coffee cultivation in North Toraja district, South Sulawesi, Indonesia Biodiversitas 18 741–51
Livesley S J, McPherson E G and Calafipietra C 2016 The urban forest and ecosystem services: impacts on urban water, heat, and pollution cycles at the tree, street, and city scale J. Environ. Qual. 45 119–24
Lohbeck M, Bongers F, Martinez-Ramos M and Poorter L 2016 The importance of biodiversity and dominance for multiple ecosystem functions in a human-modified tropical landscape Ecology 97 2772–9
Loughner C P, Allen D J, Zhang D L, Pickering K E, Dickerson R R and Landry L 2012 Roles of urban tree canopy and buildings in urban heat island effects: parameterization and preliminary results Journal of Applied Meteorology and Climatology 51 1775–1793
Marchetti M et al 2018 Inference on forest extent and ecological diversity of trees outside forest by a two-phase inventory Annals of Forest Science 75 1–14
McDonald R I, Biswas T, Sachar C, Housman I, Boucher T M, Balk D, Nowak D, Spotwood E, Stanley C K and Leyk S 2021 The tree cover and temperature disparity in US urbanized areas: quantifying the association with income across 5,723 communities PLoS One 16 e0269715
McDonald N et al 2018 Drivers and mechanisms of tree mortality in moist tropical forests New Phytol. 219 851–69
McKinney M L 2006 Urbanization as a major cause of biotic homogenization Biological Conservation 127 247–60
McPherson E G, Simpson J R, Xiao Q and Wu C 2011 Million trees Los Angeles canopy cover and bene

Page M J et al 2021 The PRISMA 2020 statement: an updated guideline for reporting systematic reviews Systematic Reviews 10 89
Pain–Orcert M and Bellefontaine R 2004 Trees Outside the Forest : a New Perspective on the Management of Forest Resources in the Tropics (Montpellier: CIRAD)
Pan Y et al 2011 A large and persistent carbon sink in the world’s forests Science 333 988–93
Pandey D 2008 Trees outside the forest (TOF) resources in India International Forestry Review 10 125–133
Paradis E and Schliep K 2019 Ape 5.0: an environment for modern phylogenetics and evolutionary analyses in R Bioinformatics 35 526–8
Peros C S, Dasgupta R, Kumar P and Johnson B A 2021 Bushmeat, wet markets, and the risks of pandemics: exploring the nexus through systematic review of scientific disclosures Environmental Science and Policy 124 1–11
Pugh T A M, Lindeskog M, Smith B, Poulter B, Arness A, Haverd V and Calle L 2019 Role of forest regrowth in global carbon sink dynamics PNAS 116 4382–4387
Putz F E and Redford K H 2010 The importance of defining ‘Forest’: tropical forest degradation, deforestation, long-term phase shifts, and further transitions Biotropica 42 10–20
Ravindranath N H, Murthy J K, Priya J, Up Gupta S, Mehra S and Nalin S 2014 Forest area estimation and reporting: implications for conservation, management and REDD+ Curr. Sci. 106 1201–6
Zomer R J, Neufeldt H, Xu J, Ahrends A, Bossio D, Trabucco A, Van Noordwijk M and Wang M 2016 Global tree cover and biomass carbon on agricultural land: the contribution of agroforestry to global and national carbon budgets Sci. Rep. 6 1–12
Zomer R J, Trabucco A, Bossio D A and Verchot L V 2008 Climate change mitigation: a spatial analysis of global land suitability for clean development mechanism afforestation and reforestation Agriculture, Ecosystems & Environment 126 67–80
Zomer R J, Trabucco A, Coe R and Place F 2009 Trees on farms: analysis of global extent and geographical patterns of agroforestry ICRAF Working paper - World Agroforestry Centre pp. 63
Zomer R J, Trabucco A, Coe R, Place F, van Noordwijk M and Xu J 2014 Trees on farms: an update and reanalysis of agroforestry’s global extent and socio-ecological characteristics Working paper 179 pp. 54 http://worldagroforestry.org/downloads/publications/PDFs/WP14064.PDF