13 Forest management for sustainable sourcing of non-timber forest products in a bioeconomy

Michelle Balasso, Sven Mutke, Jonathan P. Sheppard and James Chamberlain

Introduction

Forests have provided a wide range of vital products throughout history (Sheppard et al, 2020a). Historically focused on timber production, forest management aimed at harnessing diverse and complex ecosystems with single-goal production models, though it has evolved with changing demand for raw materials (Calama et al, 2010). Non-timber forest products (NTFPs) have been largely left out of traditional forest management planning (Chamberlain et al, 2018; Vacik et al, 2020). Despite being essential to forest health and resilience, and supporting the food security, nutrition, and wellbeing of billions of people, NTFPs have been traditionally considered secondary or minor. For this reason, there is limited technical knowledge concerning best management practices.

Development of industrial economies and the exploitation of non-renewable fossil fuels have led to the depletion and degradation of natural resources coupled with massive losses of biological diversity and potentially irreversible global changes in climate (Duchesne and Wetzel, 2011). The concept of bioeconomy was introduced to address these "grand challenges". It is based on the sustainable use of renewable resources and on nature-based solutions for providing energy, goods and services, while reducing or substituting non-sustainable consumption of fossil resources (European Commission, 2012). A sustainable bioeconomy includes production, utilisation, conservation, and regeneration of biological resources, and encompasses related knowledge, science, technology, and innovation, to provide sustainable solutions across all economic sectors (IACGB, 2020). Our focus relates to forest resources and their derivative products, in what we refer to as a "forest-based bioeconomy" (Piplani and Smith-Hall, 2021).

Derivatives from fungi, plants, and animals are the foundation of this bioeconomic vision (European Commission, 2012; McCormick and Kautto, 2013), where sustainable growth is dependent on the efficient integration of natural resource-based production sectors (BECOTEPS, 2011). The transition from "single-objective" forest management to multiple-objective sustainable forest management (SFM) is necessary for bioeconomy growth.

DOI: 10.4324/9781003245001-16

Such transformation would include all ecosystem functions and stakeholders, and recognise forests as social and ecological complex adaptive systems (Messier et al, 2013). Aiming to avoid resource depletion due to unregulated exploitation, SFM considers associated ecosystem services, such as recreation, watershed services, biodiversity conservation, and carbon benefits (Vacik et al, 2020). Following the 1992 Earth Summit in Rio, the concept expanded to include ecological, economic, and social aspects (UN, 1993), leading to a greater focus on environmental protection, biodiversity enhancement, economic viability, and the social function of forests (Baskent et al, 2008).

Fundamental for the functioning of efficient and sustainable bioeconomies, contemporary SFM principles recognise forests as more complex ecosystems, incorporating benefits such as the provisioning of food, water, materials, and cultural amenities; regulating effects of climate, floods, disease and water quality; and supporting services such as soil formation, photosynthesis, and nutrient cycling (Millennium Ecosystem Assessment, 2005). Although SFM considers the provisioning ecosystem services of goods other than wood (Chamberlain et al, 2019), it has not yet fully integrated the production and extraction of NTFPs. There are multiple reasons for this, including unfamiliarity with the economic and ecological importance of NTFPs and issues in distribution, access, and property rights (Lawrence, 2003; Sheppard et al, 2020a). For successful transition to a functioning bioeconomy, such impediments need to be overcome.

National bioeconomy strategies have been developed by more than 40 countries. These strategies are directed largely at national and regional corporate interests and renewal of the wood products industry, with the state taking a supportive rather than restrictive role for sustainable commercialisation of potential biological resources (Holmgren et al, 2020). Accordingly, the wood-based sector of the forest products industry is a main feature of bioeconomy strategies (European Commission, 2018). In general, most national strategies have not explicitly recognised NTFPs, which presents a fundamental challenge in a transition to an integrated bioeconomy. However, recently, the New EU Forest Strategy for 2030, one of the flagship initiatives of the European Green Deal, has advocated expressly for promoting the non-wood forest-based bioeconomy, to seize benefits to rural communities in forested landscapes and supporting producers' organisations (European Commission, 2019, 2021). The purpose of this chapter is to explore and integrate the concepts of forest management that consider NTFPs relative to the principles of a bioeconomy, focussing on possibilities and challenges that support or impede the integration of NTFPs into SFM. The objectives of our investigation are to:

i. Examine relevant aspects of NTFPs that may be influenced by forest management and discuss how silvicultural and forest management practices can be adjusted for the sustainable production of multiple goods.

ii. Examine challenges and factors that may encourage a transition to SFM that includes NTFPs within a bioeconomy.

Methods

The overall approach of the presented work is a narrative literature synthesis of the scientific literature relevant to the concepts of SFM and the production of NTFPs within a bioeconomy framework. Few studies have addressed these in the same conceptual and operative space. Building on the framework proposed by Sheppard et al (2020a), we modified and added elements for the integration of NTFPs into SFM as fundamentals for a bioeconomy transition (Fig. 13.1). Each position within the framework describes a factor that is significant for a transition towards sustainable forest co-management within a bioeconomy. The core of the framework are the complex relationships between "Forest ecosystem", "Social system" and "Governance" (white hexagons); these three primary nodes are influenced by sub-nodes (small hexagons) which describe the mechanisms that pressure the transition. Finally, external influences (circles) are given; these imply stimuli that can activate changes within the framework itself.

The sustainable co-production of timber and non-timber alongside associated ecosystem services entails important changes in forest resource management. Simultaneous production of contrasting products is technically possible yet requires identification of temporal and spatial constraints, ecological requirements of multiple species, site conditions, market and cost issues, and management. Forest management can accept silvicultural integration of NTFPs, however, other factors have pivotal roles in the sustainable management of forest resources. Overall, the governance (e.g., policies, regulations, rules, and norms) and management related actions (e.g., plans, inventory, growth, and yield estimations, reporting and certification) that exist for timber are needed for NTFPs. To address ecological and social complexities requires governance mechanisms that satisfy multiple stakeholder interests and mitigate potential conflicts (Messier et al, 2015; Borgström, 2018; Sheppard et al, 2020a).

We focus on two major challenges: (i) the ecological aspects of co-production of timber and non-timber products and (ii) necessary management actions to integrate co-production within the bioeconomy concept. We investigated these challenges targeting and collating scholarship that allowed us to analyse their integration using narrative synthesis (Jesson and Lacey, 2006). Our approach aimed at encompassing the relevant literature, drawing findings of diverse studies together, following a narration pathway that moves from traditional forest management practices towards integrative approaches for a bioeconomy. Hence, other specialist forms of synthesis, such as meta-analyses or systematic reviews, would have been less suitable to our aim (Popay et al, 2006).

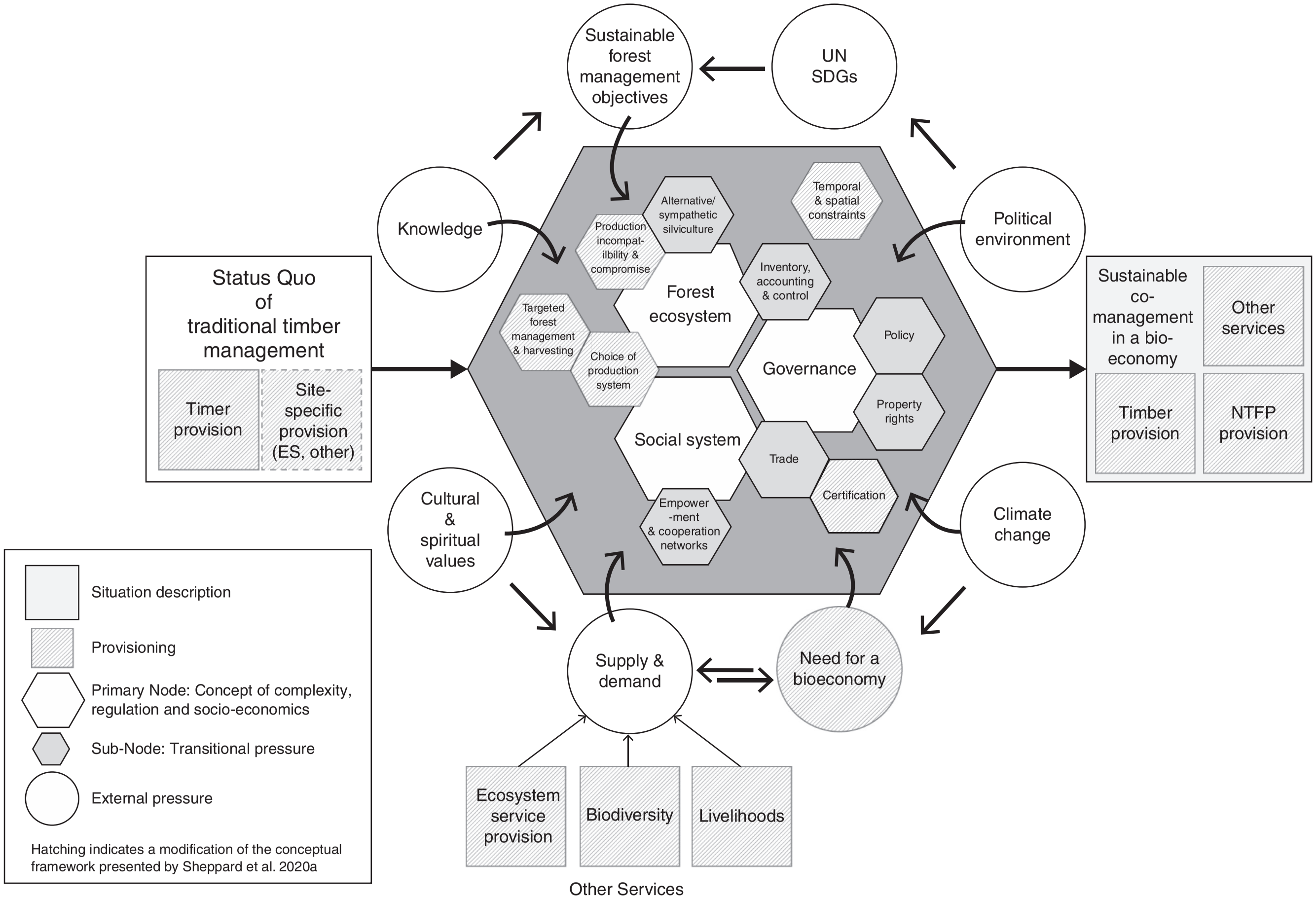

Figure 13.1. Conceptual framework for integration of NTFPs into forest management to transition into a bioeconomy (modified from Sheppard et al, 2020a).

We also avoided a systematic review of the literature on the single concepts, and instead built a framework to understand the connectedness of the concepts to present the compatibility of NTFPs, forest management, and bioeconomy. Our initial search drew from relevant works published on these topics and their respective reference lists (Guariguata et al, 2010; Miina et al, 2020; Sheppard et al, 2020a). This was supplemented by search engine queries using the terms "NTFP(s)", "Sustainable Forest Management", "Integrated Forest Management", "Bioeconomy", "Silviculture and NTFP(s)". We prioritised scientific peer-reviewed publications and acknowledged European scale project reports.

Results and discussion

Silvicultural practices for sustainable production of multiple goods

Co-existing, symbiotic, or parasitic NTFP species are all reliant on trees and they habitat they provide influenced by the forest ecosystem. Contemporary forestry practices impact NTFPs occurrence, survival, and abundance through varied mechanisms. Table 13.1 presents examples of relationships between silvicultural practices, NTFPs, and possible approaches for co-production.

Silvicultural treatments and disturbance events quickly change the structure and productivity of forests by modifying biophysical aspects (Aussenac, 2000) and indirectly impact NTFPs that depend on pre-existing environmental conditions (Sinha and Brault, 2005; Sheppard et al, 2020b). Timber harvesting, for example, especially over large areas, drastically increases solar radiation in forest stands (Pereira et al, 2002), which may positively impact species that benefit from canopy gaps (Costa et al, 2002) or negatively impact those that prefer shade. In boreal coniferous forests, understory berry-producing plants, such as bilberry (*Vaccinium myrtillus* L.) and cowberry (*Vaccinium vitis-idaea* L.), are highly affected by light conditions. Bilberry production decreases significantly in logged stands with increasing light and the creation of drier conditions (Granath et al, 2018). A possible approach for the co-existence of berries and timber harvesting is to adjust logging rates, with canopy cover retainment providing conditions for the plants to thrive, favouring berry occurrence while extracting adequate volumes of timber over a rotation.

Logging, in general, can impact forest flora and fauna diversity, presenting serious risks to biodiversity and wildlife. Reduced-impact logging techniques designed to mitigate risks have shown positive results in maintaining species richness and abundance while allowing timber harvesting (Azevedo-Ramos et al, 2006). Methods and intensities of timber extraction, and the amount of canopy and slash retained, influence the rate and composition of understory growth and subsequent product yields (Bergstedt and Milberg, 2001; Soriano et al, 2012). Soil characteristics are greatly changed due to forestry

Table 13.1. Examples of relationships between silvicultural practices, NTFPs, and possible co-production approaches.

Forest operation	*Description of impact*	*Example*	*Possible approach*
Timber harvesting	Solar radiation increase: positive for species benefitting from canopy gaps, negative for species requiring shade	Cowberry production increases about 80-fold relative to unlogged stands; bilberry production is reduced to zero in logged stands (Granath et al, 2018)	Bilberry production improved through selective logging
Logging operations	Soil compaction and erosion: characteristics of the soil surface	Can affect plant species' diversity and abundance in logged areas	Restriction of logging to designated routes and low rainfall season. Improved infrastructure considering effects on the understory and soils
Artificial regeneration methods (e.g., full-area high-density planting or sowing, and brush clearing)	Decrease opportunities for pioneer and early succession NTFP species to establish	Species restocking and weed control practices (Guariguata et al, 2010)	Deadwood retention: improvement of forest floor micro-dynamics and bio-diversity, NTFP habitat promotion, and thus, NTFP production (Lambini et al, 2018)
Forest management for high-quality timber products	Favours straight, defect-free stems and uniform crowns: conflict with resin and sap production	Syrup derived from sugar maple: sap production is directly related to canopy size and amount of foliage (Farrell and Chabot, 2012)	Retention of selected individuals with poor form for sap/fruit production, focus on stand production value, not individual trees (Sheppard et al, 2016)
	Application of qualitative pruning aiming at an increase in the quality and volume of timber	Reduce possible production of fruits, berries, or nuts, and make harvesting of fruit and nuts more difficult as production is pushed higher in the tree	
Silvicultural thinning	Can cause localised increases in temperature and decreases relative humidity, which may favour or endanger understory plant communities	Increase in European beech (*Fagus sylvatica* L.) associated ectomycorrhizal fungi Saffron milk cap (*Lactarius* group *deliciosus*) production increases with a decreasing density of older pine stands through thinning (Liu et al, 2016)	Thinning regimes modified in terms of intensity and frequency to mitigate undesirable consequences on NTFP species

operations (Šušnjar et al, 2006; Jamshidi et al, 2008), affecting plant species diversity and abundance (Wei et al, 2015).

High-quality timber production requires large stems, also a requirement to produce sap for sugar maple (*Acer saccharum* Marshall) syrup. Trees are generally thinned, resulting in a wider spacing (Farrell and Chabot, 2012; Chamberlain et al, 2020). Forest management decisions are thus challenged with trade-offs, as these silvicultural practices may increase sap production but may not favour timber quality, while altering the characteristics of the forest floor and the ground flora (Aussenac, 2000). However, gaps created by thinning can increase competition on the forest floor, resulting in a shift of the plant community to another successional group.

Ectomycorrhizal mushroom production is linked to the growth and health of associated host trees and maintenance of the symbiosis between the tree and fungi. Success of the symbiosis depends on the amount of light and moisture reaching the understory as well as ambient temperature. For example, application of a thinning treatment may change the number of mushroom species dependent on microclimatic requirements (Pilz et al, 2006; Crockatt, 2012; Ries et al, 2017). This influence is linked to the number of trees removed, frequency of management, and thinning approach (Bonet et al, 2010; Liu et al, 2016).

Approaches for integration of NTFPs in forest management in the bioeconomy

Successful integration of NTFPs in forest management in the context of a bioeconomy requires consideration and planning for impacts of product extraction on other products. While timber harvesting and logging can change the presence, production, extraction, and management of NTFPs, the production and harvesting of NTFPs has consequences on tree growth and timber quality.

Differences in the effects of silvicultural treatments may depend on whether the NTFP is part of the tree (e.g., bark, fruit, boughs) or dependent on an attribute of the tree such as nutrients, moisture, or shade. Some NTFPs are harvested from the same trees managed for timber (e.g., resin-tapped pines, sap-tapped birch or maple, bark-stripped cork oaks, or fruit-bearing trees) and, hence, their distribution and occurrence within forest stands affects silvicultural prescriptions and practices. In these cases, impacts are not mutually exclusive but shared (Gaoue and Ticktin, 2007; Tomé et al, 2020); integrating forest floor species into management decisions impacts the frequency and intensity of entry into stands.

The presence, survival, and productivity of NTFPs can be encouraged through innovative silvicultural prescriptions that mix species with multiple objectives that advance "close-to-nature" approaches (Miina et al, 2020). Forest management for multiple products may consider alternative spatial compositions; forest edges provide refuge for valuable and productive NTFPs, especially those needing more light and specific canopy conditions not found within the forest interior. Forest edges are transitional zones between forest and non-forest habitats with unique management opportunities. In these areas, timber production goals may complement management regimes that favour NTFPs production and create a more resilient and sustainable landscape matrix.

Agroforestry provides more resilient landscapes by mixing trees and agricultural crops on the same land. The role of agroforestry in the provisioning of NTFPs and increasing food security is well documented (Sheppard et al, 2020c). One agroforestry example covering several million hectares of open oak woodlands in the Mediterranean combines cork with wood pasture, acorn mast, or rotational farming as secondary objectives. Cork woodlands are highly esteemed natural and cultural landscapes protected from unauthorised changes due to their biodiversity and economic relevance (Tomé et al, 2020).

Even in nearly pristine forest ecosystems, forest farming can play a role in reducing pressure on understory plant populations while allowing commercial production (Chamberlain et al, 2009). Forest farming may be applied for a multi-purpose management approach, in which the production of crops is enhanced underneath the canopy of forest trees. Particularly, forest farming for native understory NTFPs has a role in reducing pressure on wild populations while allowing for commercial production from close-to-nature systems (Small et al, 2014).

The successful integration of NTFPs benefits may require adopting techniques that are seldom used in conventional forest management. These may include:

- Grafting, promotion of alternative branching architecture and earlier fruit production (Mutke et al, 2011; Sheppard et al, 2016).
- Inoculation of planting stock may promote the growth of desired mushrooms, truffles, and conks (Kurttila et al, 2019).
- Transplanting rootstock from natural populations to propagate understory plants in agroforestry settings (Small et al, 2014).

Challenges for transitions to a forest-based bioeconomy

A shown in the three primary nodes of the conceptual framework outlined in Fig. 13.1, challenges for the transition of forest management towards a bioeconomy hinge on modification within the forest ecosystem (incorporating forest management), social system, and governance. All these elements are acting as central (interlinked) pivots for transition.

Integration of forest management practices into the bioeconomy requires application of forestry management practices and accurate consideration of the principles of production, utilisation, conservation, and regeneration of timber and NTFPs. Silvicultural approaches for producing timber can be adapted to include other products if the impacts on these are more fully considered. Impacts can be evaluated in a framework of production compatibility, considering the spectra of relationships between forest products. Relationships range from synergistic compatible production to incompatibility, requiring trade-offs in production (Miina et al, 2020), as presented in Table 13.2. When compatibility is realised, multiple products can be achieved sustainably, although management decisions imply some trade-offs. Cases, where incompatibility is present, require a management choice which favours one product type over others.

When relationships are considered, forest management choices can follow, to sustain and support co-production and trade-offs. For example, in Spain, timber growth may be reduced in areas where cork, pinecones, resin, acorns, and pasture are specified co-management goals. However, in general, management plans for timber-oriented forests lack prescriptions for NTFPs. To integrate NTFPs in forest management planning, decision-makers and silviculturists must navigate the type and magnitude of interventions, and compromises between timber and non-timber production goals must be assessed.

Modification of forest management practices, such as rotation length or timing and intensity of thinning, requires coordination between managers, producers, and harvesters, and requires a fundamental change in the governance of forests and forest products. To drive the transformation towards sustainable co-production, governance of forest resources and consideration

Table 13.2. Types of multiple-product production compatibility and examples.

Type of relationship	*Description*	*Example*
Synergistic compatible production	Full compatibility without trade-offs: sustainable production of multiple goods	Climbing palms favoured by the creation of logging gaps (Guariguata et al, 2011)
Competitive production	Trade-offs are required, depending on the value of timber vs NTFPs	Examples for higher-value NTFPs: Brazil nut forests (Guariguata et al, 2008) Mediterranean pine nuts (Mutke et al, 2011) Eastern lime honey in the Russian Far East (Domènech et al, 2019)
	Trade-offs are required, depending on factors such as accessibility	NTFP harvesters are denied access to the resource, where logging operations exclude local NTFP collectors (Rist et al, 2012)
Incompatibility	No trade-offs are possible: one product type is favoured over the other	Trees with high-timber and non-timber values: removal of the tree directly conflicts with NTFP harvesting (Herrero-Jáuregui et al, 2009)

of associated social systems are central (Sheppard et al, 2020a). Forest governance for a broader portfolio of NTFPs within a bioeconomy needs to consider the views, behaviours, and objectives of a diverse set of stakeholders (Vacik et al, 2020). The governance process should adapt to local situations, considering the type of products and the extent that benefits derive from economic and cultural values. Successful forest policy instruments that support sustainable management, while considering access and rights to the products, will consider stakeholders, market dynamics, and other affected ecosystem services (Martínez de Arano et al, 2021).

Accessibility in terms of right of access and extraction of NTFPs is a clear forest governance issue. Regulations and conventions concerning access vary between administrative authorities, often on a federal or national basis, and can be governed by radically different laws and cultural practices, as well as local traditions (Nichiforel et al, 2018). In some countries, all "fruits of the land" are legally considered property of the landowner restricting community access to NTFPs (Maguigad, 2020). Conversely, some countries operate under the norm of everyman's right, where the harvest of products such as wild berries, mushrooms, and flowers is unregulated (common-pool resources). In these cases, forest owners have rights to the trees and the resultant timber but do not have exclusive property rights over commercial NTFP collection (Hamunen et al, 2019). Under this concept, forest landowners receive no added economic value from management that integrates NTFPs (Sheppard et al, 2016; Sheppard, 2017), thus having no stimulus for integrated management (Sheppard et al, 2020a). With recent increased commercialisation, such an everyman's right cultural norm has been confounded (Hamunen et al, 2019). As market demands increase, the engagement of seasonal non-resident pickers has generated conflicts with local harvesters, for example, in the case of mushroom picking. Solving these conflicts requires concerted actions by forest, municipal, police, judicial, and social authorities (Górriz-Mifsud et al, 2017).

The integration of non-timber and timber production in a bioeconomy is complex and requires adaptative management strategies (Lawrence, 2003) that incorporate forest governance with the capacity to make science-based decisions to account for multiple stakeholder interests. Production of multiple and sometimes contrasting products is technically possible, however, trade-offs and compromises must be reached. Major challenges impede the transition to a forest-based bioeconomy that include NTFPs, among which the lack of recognition, knowledge on integrated management, harvest, and importance for local and global economies, are determinant factors. For successful integration of NTFPs into forest management, in the bioeconomic vision of sustainable production of goods, actions to account for and make prescriptions to produce multiple goods are needed. Ultimately the greatest challenge to overcome is recognition that NTFPs are natural resources with value to society and require management to ensure that present and future generations have access to and can benefit from them.

Conclusions

Effective integration of NTFPs into forest management can aid the transition towards a bioeconomy where sustainable co-production is paramount. There are numerous examples where synergies can be realised, and multiple products can be sustainably achieved despite technical challenges. Forest management for a bioeconomy with NTFPs requires major changes in how silvicultural prescriptions are planned and carried out. Moreover, modifications to policy instruments alongside structural and technical modifications in the governance of forest resources and management would motivate and encourage transition to a forest-based bioeconomy with NTFPs. All of this is dependent on embracing stakeholders, markets, and other social dynamics. In conclusion, to achieve the goals of a bioeconomy for sustainable, integrated, renewable production and circulation of NTFPs, increased attention, and alternative and innovative co-production methods, to integrated forest management practices are needed.

Key messages for the bioeconomy and NTFPs

- Integration of non-timber species into forest management has the potential to produce timber with other products, harmonised with the principles of a bioeconomy.
- An integrated forest management approach is needed, where silvicultural, managerial, and governance practices consider and incorporate appropriate actions.
- Challenges need to be considered, among which NTFPs recognition, inventory, reporting, trade, certification, and governance are fundamental.
- For the sustainable production of NTFPs, identification and consideration of synergies and trade-offs need to be made at the local and governmental scale, informed by knowledge about species ecology.

Note

The findings and conclusions in this publication are those of the author(s) and should not be construed to represent any official USDA or U.S. Government determination or policy.

References

Aussenac, G. (2000) Interactions between forest stands and microclimate: ecophysiological aspects and consequences for silviculture. *Annals of Forest Science* 57 (3): 287–301.

Azevedo-Ramos, C., de Carvalho, O. and do Amaral, B.D. (2006) Short-term effects of reduced-impact logging on eastern Amazon fauna. *Forest Ecology and Management* 232 (1): 26–35.

Baskent, E.Z., Keles, S. and Yolasigmaz, H.A. (2008) Comparing multi-purpose forest management with timber management, incorporating timber, carbon and oxygen values: a case study. *Scandinavian Journal of Forest Research* 23 (2): 105–120.

BECOTEPS. (2011) *The European bioeconomy in 2030: delivering sustainable growth by addressing the grand societal challenges*. Available from: https://greengrowthknowledge.org/research/european-bioeconomy-2030-delivering-sustainable-growth-addressing-grand-societal-challenges.

Bergstedt, J. and Milberg, P. (2001) The impact of logging intensity on field-layer vegetation in Swedish boreal forests. *Forest Ecology and Management* 54(1–2):105–115.

Bonet, J.A.B.A., Palahí, M.P., Colinas, C.C., Pukkala, T.P., Fischer, C.R.F.R., Miina, J.M. and Aragón, J.M. (2010) Modelling the production and species richness of wild mushrooms in pine forests of the Central Pyrenees in northeastern Spain. *Canadian Journal of Forest Research* 40 (2): 347–356.

Borgström, S. (2018) Reviewing natural resources law in the light of bioeconomy: Finnish forest regulations as a case study. *Forest Policy and Economics* 88: 11–23.

Calama, R., Tomé, M., Sánchez-González, M., Miina, J., Spanos, K. and Palahí, M. (2010) Modelling non-wood forest products in Europe: a review. *Forest Systems* 19: 69–85.

Chamberlain, J.L., Mitchell, D., Brigham, T., Hobby, T., Zabek, L. and Davis, J. (2009) *Forest farming practices. North American Agroforestry: An Integrated Science and Practice*, 2nd edition, pp. 1–38.

Chamberlain, J.L., Darr, D. and Meinhold, K. (2020) Rediscovering the contributions of forests and trees to transition global food systems. *Forests* 11 (10): 1098.

Chamberlain, J.L., Emery, M.R. and Patel-Weynand, T. (2018) Assessment of non-timber forest products in the United States under changing conditions. *General Technical Report SRS-232, US Forest Service, Southern Research Station*, 232, pp. 1–268.

Chamberlain, J.L., Small, C.J. and Baumflek, M. (2019) Sustainable production of temperate and boreal non-timber forest products: examples from North America. In Stanturf J. (Ed.) *Achieving sustainable forestry. Volume 1. Boreal and Temperate Forests*, Burleigh Doods Science Publishing, Cambridge, pp. 755–790.

Costa, F.R.C., Senna, C. and Nakkazono, E.M. (2002) Effects of selective logging on populations of two tropical understory herbs in an Amazonian forest. *Biotropica* 34 (2): 289–296.

Crockatt, M.E. (2012) Are there edge effects on forest fungi and if so, do they matter? *Fungal Biology Reviews* 26 (2): 94–101.

Domènech, R., Tracy, E.F., Rovira, M. and Lepeshkin, E. (2019) *Beekeeping in Primorsky Province: challenges and opportunities*. Forest Science and Technology Centre of Catalonia (CTFC) and WWF Russia. Available from: https://amurinfocenter.org/upload/iblock/14d/Beekeeping-in-Primorsky-province-WWF-CTFC.pdf.

Duchesne, L.C. and Wetzel, S. (2011) The bioeconomy and the forestry sector: changing markets and new opportunities. *The Forestry Chronicle* 79 (5): 860–864.

European Commission, Directorate-General for Research and Innovation (2012) *Innovating for sustainable growth: a bioeconomy for Europe*, Publications Office. https://data.europa.eu/doi/10.2777/6462.

European Commission (2019) *The European green deal*. COM/2019/640 final. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.

European Commission (2021) *New EU forest strategy for 2030*. COM/2021/572 final. https://ec.europa.eu/environment/strategy/forest-strategy_en.

Farrell, M. and Chabot, B. (2012) Assessing the growth potential and economic impact of the U.S. maple syrup industry. *Journal of Agriculture, Food Systems, and Community Development* 2: 11–27.

Gaoue, O.G. and Ticktin, T. (2007) Patterns of harvesting foliage and bark from the multi-purpose tree Khaya senegalensis in Benin: variation across ecological regions and its impacts on population structure. *Biological Conservation* 137 (3): 424–436.

Górriz-Mifsud, E., Marini Govigli, V. and Bonet, J.A. (2017) What to do with mushroom pickers in my forest? Policy tools from the landowners' perspective. *Land Use Policy* 63: 450–460.

Granath, G., Kouki, J., Johnson, S., Heikkala, O., Rodríguez, A. and Strengbom, J. (2018) Trade-offs in berry production and biodiversity under prescribed burning and retention regimes in boreal forests. *Journal of Applied Ecology* 55 (4): 1658–1667.

Guariguata, M.R., García-Fernández, C., Sheil, D., Nasi, R., Herrero-Jáuregui, C., Cronkleton, P. and Ingram, V. (2010) Compatibility of timber and non-timber forest product management in natural tropical forests: perspectives, challenges, and opportunities. *Forest Ecology and Management* 259 (3): 237–245.

Guariguata, M.R., Cronkleton, P., Shanley, P. and Taylor, P.L. (2008) The compatibility of timber and non-timber forest product extraction and management. *Forest Ecology and Management* 256 (7): 1477–1481.

Guariguata, M.R., García-Fernández, C., Nasi, R., Sheil, D., Herrero-Jáuregui, C., Cronkleton, P., Ndoye, O. and Ingram, V. (2011) Timber and non-timber forest product extraction and management in the tropics: towards compatibility? In: Shackleton, S., Shackleton, C., and Shanley, P. (Eds.) *Non-timber forest products in the global context. Tropical Forestry*. Berlin: Springer, pp. 171–188.

Hamunen, K., Kurttila, M., Miina, J., Peltola, R. and Tikkanen, J. (2019) Sustainability of Nordic non-timber forest product-related businesses – A case study on bilberry. *Forest Policy and Economics* 109: 102002.

Herrero-Jáuregui, C., García-Fernández, C., Sist, P.L.J. and Casado, M.A. (2009) Conflict of use for multi-purpose tree species in the state of Pará, eastern Amazonia, Brazil. *Biodiversity and Conservation* 18 (4): 1019–1044.

Holmgren, S., D'Amato, D. and Giurca, A. (2020) Bioeconomy imaginaries: a review of forest-related social science literature. *Ambio* 49 (12): 1860–1877.

IACGB (2020) *International advisory council on global bioeconomy. Expanding the sustainable bioeconomy – Vision and Way Forward*. Communiqué of the Global Bioeconomy Summit 2020. Available from: https://gbs2020.net/wp-content/uploads/2020/11/GBS2020_IACGB-Communique.pdf.

Jamshidi, R., Jaeger, D., Raafatnia, N. and Tabari, M. (2008) Influence of two ground-based skidding systems on soil compaction under different slope and gradient conditions. *International Journal of Forest Engineering* 19 (1): 9–16.

Jesson, J. and Lacey, F. (2006) How to do (or not to do) a critical literature review. *Pharmacy Education* 6 (2): 139–148.

Kurttila, M., Butler, B.J., Hujala, T., Miina, J., Vanhanen, H. and Vacik, H. (2019) The diversifying use of family forests – Opportunities for new services. In: Hujala, T., Toppinen, A., and J. Butler, B. (Eds.) *Services in family forestry. World Forests*. Springer International Publishing, pp. 67–81.

Lambini, C.K., Nguyen, T.T., Abildtrup, J., Pham, V.D., Tenhunen, J. and Garcia, S. (2018) Are ecosystem services complementary or competitive? An econometric analysis of cost functions of private forests in Vietnam. *Ecological Economics* 147: 343–352.

Lawrence, A. (2003) No forest without timber? *International Forestry Review* 5 (2): 87–96.

Liu, B., Bonet, J.A., Fischer, C.R., Martínez de Aragón, J., Bassie, L. and Colinas, C. (2016) Lactarius deliciosus Fr. soil extraradical mycelium correlates with stand fruitbody productivity and is increased by forest thinning. *Forest Ecology and Management* 380: 196–201.

Maguigad, E. (2020) *Assessment of policies on non-timber forest products (NTFPS) in southeast Asia towards enabling community forestry enterprises*. Available from: https://ntfp.org/2020/10/assessment-of-policies-on-ntfps-regional-summary/.

Martinez de Arano I., Maltoni S., Picardo A., Mutke S., (coord.) (2021) *Non-wood forest products for people, nature and the green economy. Recommendations for policy priorities in Europe. A white paper based on lessons learned from around the Mediterranean*. Series Knowledge to Action n° 5. EFI and FAO, Barcelona, p. 85 https://doi.org/10.36333/k2a05 ISBN: 978-952-7426-7408-1

McCormick, K. and Kautto, N. (2013) The bioeconomy in Europe: an overview. *Sustainability* 5 (6): 2589–2608.

Messier, C., Puettmann, K., Chazdon, R., Andersson, K.P., Angers, V.A., Brotons, L., Filotas, E., Tittler, R., Parrott, L. and Levin, S.A. (2015) From management to stewardship: viewing forests as complex adaptive systems in an uncertain world. *Conservation Letters* 8 (5): 368–377.

Messier, C., Puettmann, K.J. and Coates, K.D. (2013) *Managing forests as complex adaptive systems: building resilience to the challenge of global change*. Routledge, London.

Miina, J., Kurttila, M., Calama, R., de-Miguel, S. and Pukkala, T. (2020) Modelling non-timber forest products for forest management planning in Europe. *Current Forestry Reports* 6 (4): 309–322.

Millennium Ecosystem Assessment. (2005) *Ecosystems and human well-being: synthesis*. Washington, DC: Island Press.

Mutke, S., Calama, R., González-Martínez, S.C., Montero, G., Gordo, F.J., Bono, D. and Gil, L. (2011) Mediterranean stone pine: botany and horticulture. In: *Horticultural reviews*. John Wiley & Sons, Ltd, pp. 153–201.

Nichiforel, L., Keary, K., Deuffic, P., Weiss, G., Thorsen, B.J., Winkel, G., Avdibegović, M., Dobšinská, Z., Feliciano, D., Gatto, P., Gorriz Mifsud, E., Hoogstra-Klein, M., Hrib, M., Hujala, T., Jager, L., Jarský, V., Jodłowski, K., Lawrence, A., Lukmine, D., Pezdevšek Malovrh, Š., Nedeljković, J., Nonić, D., Krajter Ostoić, S., Pukall, K., Rondeux, J., Samara, T., Sarvašová, Z., Scriban, R.E., Šilingien☒, R., Sinko, M., Stojanovska, M., Stojanovski, V., Stoyanov, N., Teder, M., Vennesland, B., Vilkriste, L., Wilhelmsson, E., Wilkes-Allemann, J., Bouriaud, L. (2018) How private are Europe's private forests? A comparative property rights analysis. *Land Use Policy* 76: 535–552.

Pereira, R., Zweede, J., Asner, G.P. and Keller, M. (2002) Forest canopy damage and recovery in reduced-impact and conventional selective logging in eastern Para, Brazil. *Forest Ecology and Management* 168 (1): 77–89.

Pilz, D., Molina, R. and Mayo, J. (2006) Effects of thinning young forests on chanterelle mushroom production. *Journal of Forestry* 104 (1): 9–14.

Piplani, M. and Smith-Hall, C. (2021) Towards a global framework for analysing the forest-based bioeconomy. *Forests* 12 (12): 1673.

Popay, J., Roberts, H., Sowden, A., Petticrew, M., Arai, L., Rodgers, M., Britten, N., Roen, K. and Duffy, S. (2006) *Guidance on the conduct of narrative synthesis in systematic reviews*. Lancaster University.

Ries, L., Murphy, S.M., Wimp, G.M. and Fletcher, R.J. (2017) Closing persistent gaps in knowledge about edge ecology. *Current Landscape Ecology Reports* 2 (1): 30–41.

Rist, L., Shanley, P., Sunderland, T., Sheil, D., Ndoye, O., Liswanti, N. and Tieguhong, J. (2012) The impacts of selective logging on non-timber forest products of livelihood importance. *Forest Ecology and Management* 268: 57–69.

Sheppard, J.P., Chamberlain, J., Agúndez, D., Bhattacharya, P., Chirwa, P.W., Gontcharov, A., Sagona, W.C.J., Shen, H., Tadesse, W. and Mutke, S. (2020a) Sustainable forest management beyond the timber-oriented status quo: transitioning to co-production of timber and non-wood forest products – A global perspective. *Current Forestry Reports* 6 (1): 26–40.

Sheppard, J.P., Santos e Silva, C., Louro, R., Stara, K., Belova, O. and Spiecker, H. (2020b) Identification and ecology of NWFP species. In: Vacik, H., Hale, M., Spiecker, H., Pettenella, D., and Tome, M. (Eds.) *Non-wood forest products in Europe. Ecology and management of mushrooms, tree products, understory plants and animal products*. Norderstedt: BoD, pp. 19–43.

Sheppard, J.P., Bohn Reckziegel, R., Borrass, L., Chirwa, P.W., Cuaranhua, C.J., Hassler, S.K., Hoffmeister, S., Kestel, F., Maier, R., Mälicke, M., Morhart, C., Ndlovu, N.P., Veste, M., Funk, R., Lang, F., Seifert, T., du Toit, B. and Kahle, H.-P. (2020c) Agroforestry: an appropriate and sustainable response to a changing climate in Southern Africa? *Sustainability* 12 (17): 6796.

Sheppard, J.P. (2017) *Multipurpose trees & non-wood forest products: a challenge and opportunity for European silviculture*. Interconnecting Forests, Science and People: 125th IUFRO Anniversary Congress 2017. Freiburg. 18–22 September 2017.

Sheppard, J.P., Mangold, R. and Spiecker, H. (2016) *Revised silvicultural guidelines for selected MPT and NWFP. Startree Deliverable 2.3*. European Commission.

Sinha, A. and Brault, S. (2005) Assessing sustainability of non-timber forest product extractions: how fire affects sustainability. *Biodiversity & Conservation* 14 (14): 3537–3563.

Small, C.J., Chamberlain, J.L. and Nuckols, C.M. (2014) Failure of black cohosh (*Actaea racemosa* L.) rhizome transplants: potential causes and forest farming implications. *Agroforestry Systems* 88 (5): 815–822.

Soriano, M., Kainer, K.A., Staudhammer, C.L. and Soriano, E. (2012) Implementing multiple forest management in Brazil nut-rich community forests: effects of logging on natural regeneration and forest disturbance. *Forest Ecology and Management* 268: 92–102.

Šušnjar, M., Horvat, D. and Šešelj, J. (2006) Soil compaction in timber skidding in winter conditions. *Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering* 27 (1): 3–15.

Tomé, M., Sheppard, J.P., Alma, M.H., Carrasquinho, I., Christensen, C.J., Hellström, J., Kurttila, M., Marnila, P., Mattila, P., Miina, J., Mutke, S., Paulo, J.A., Palma, J.H., Pihlava, J.M., Pignatti, G., Sanchéz-González, M., Silva, C.S., Soares, P., Vanhanen, H. (2020) Non-wood tree products in Europe. In: *Non-wood forest products in Europe. Ecology and management of mushrooms, tree products, understory plants and animal products. Outcomes of the COST Action FP1203 on European NWFPs*, pp. 263–302.

UN. (1993) *Agenda 21- United Nations conference on environment & development*. Rio de Janeiro, Brazil: United Nations Division for Sustainable Development. Available from: https://sustainabledevelopment.un.org/content/documents/Agenda21.pdf.

Vacik, H., Wiersum, F., Mutke, S., Kurttila, M., Sheppard, J., Wong, J., de Miguel, S., Nijnik, M., Spiecker, H., Miina, J., Huber, P., Melnykovych, M., Tsioras, P., Abraham, E., Enescu, M. and Kyriazopoulos, A. (2020) Considering NWFP in multi-purpose forest management. In: Vacik, H., Hale, M., Spiecker, H., Pettenella, D. and Tome, M. *2020, Non-wood forest products in Europe. Ecology and management of mushrooms, tree products, understory plants and animal products*. Norderstedt: BoD, pp. 79–123.

Wei, L., Villemey, A., Hulin, F., Bilger, I., Yann, D., Chevalier, R., Archaux, F. and Gosselin, F. (2015) Plant diversity on skid trails in oak high forests: A matter of disturbance, micro-environmental conditions or forest age? *Forest Ecology and Management* 338: 20–31.