A multi-disciplinary perspective to nuance the narrative of tree planting as a nature-based solution

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Abstract

From global nature conservation policies to carbon off-set private initiatives, the focus on tree promotion, and tree planting in particular, as a nature-based solution to global environmental crises such as climatic change and biodiversity loss dominates the current discourse. Yet, this fixation on trees does not reflect a scientific consensus on the benefits of tree planting across diverse ecosystems and can have problematic implications from both an ecological and socio-political perspective. In this paper, we synthesise cross-disciplinary insights to challenge the common storyline of tree planting as a one-size-fits-all, nature-based solution to climate change and biodiversity loss. We discuss the appeal of tree planting as a panacea, and how this conflicts with reality, in which a diverse range of stakeholders represent various perspectives and pursue a plurality of goals. We assess the communicative aspects of trees and forests, exploring the symbolic power of a ‘tree’ and how practices in remote-sensing and scientific modelling reinforce the dominant tree planting narrative. We then reflect on the ecological and human contexts that need to be considered in planning of tree planting and how historical ecological baselines continue to influence ecosystem management goals. Finally, we explore how current conservation narratives value forest over other kinds of nature and demonstrate the important – but overlooked – role that non-forest landscapes such as open and semi-open vegetation play in climate change mitigation and biodiversity conservation. We conclude that we need to rethink the dominant tree-planting narrative, being mindful and critical of the socio-political drivers behind tree planting initiatives and potential biases, and allow ecological and sociocultural contexts to inform tree-promotion efforts and appropriateness.

1. Introduction

Climate action failure and biodiversity loss are in the top five risks to the global economy and society (World Economic Forum, 2020). As a result, ambitious environmental policies are being proposed, aiming to address the dual crises of climate change and biodiversity loss. This shift towards green policies has led to a renewed interest in nature-based solutions (NbS): actions to protect, manage and restore ecosystems with the objective to address major societal challenges, while providing a range of benefits for people and the ecosystems on which they depend (Seddon et al., 2020b). The use of trees as carbon sinks to remove significant amounts of greenhouse gasses from the atmosphere has been a focus of much interest in the public, scientific and political spheres (Bastin et al., 2019; Keesstra et al., 2018). Policy reports, like the renowned Stern Review on the Economics of Climate Change, promote tree planting as ‘an excellent long-term policy’, and state that forest cover can be increased cost-effectively in most areas of the world, promoting avoided deforestation, reforestation and afforestation (Stern, 2007). More recently, the European Commission 2030 Biodiversity Strategy ‘Bringing nature back into our lives’ proposes to plant at least 3 billion additional trees in the EU by 2030 (European Commission, 2020). Recommendations to achieve these objectives range from the promotion of large-scale reforestation (tree planting in previously forested areas), afforestation (creation of newly forested areas), and tree plantations to increase tree cover globally. As such, planting trees has become a generalizable and universalized technology as an NbS to address climate change. This current focus on tree planting has been addressed and criticized both from a socio-political (Griscom et al., 2020) and ecological (Friedlingstein et al., 2019; Veldman et al., 2019) point of view, but an integrated conversation between these disciplines is still missing. Here, we explore this topic from a broad and multidisciplinary perspective, exploring how trees came to dominate the NbS discourse, and offering alternative narratives to tree planting as a one-size-fits-all NbS.

For illustration, seven percent (290 million ha) of the forest area worldwide are plantation forests, of which 45% (131 million ha) are planted in intensively managed plantations established mainly for productive purposes (UNEP and FAO, 2020). The type of tree planting depends on the motives behind the planting, yet in current tree planting initiatives or promotion, this distinction is not always clear (Faruqi et al., 2018). Tree plantations for biofuel production and for forest restoration are both considered as NbS (Seddon et al., 2020a). Therefore, in this manuscript we will refer to tree planting in general, unless otherwise specified. We also do not consider ‘forests’ to be binary defined by a certain tree threshold, but use this term to refer to forest and woodland ecosystems with complex ecosystem functions and biotic composition (Griffith et al., 2017; Swanson et al., 2021).

While some scientists promote tree planting as the solution to climate change mitigation (e.g. Bastin et al. 2019), others have called for caution to indiscriminate implementation. They warn of potential undesirable

67 outcomes and generally argue against tree planting as a simple solution to all environmental crises (see e.g.
68 Bond et al., 2019; Griscom et al., 2020; Lewis et al., 2019; Seymour, 2020; van Noordwijk, 2020). Regardless
69 of the intentions behind tree planting and obvious benefits given the right circumstances, these initiatives
70 become problematic when they are promoted as a simple, silver-bullet solution to overcome a range of
71 environmental problems (Holl and Brancalion, 2020). Without considering their ecological context, planting
72 trees does not automatically yield functional forest ecosystems, and the capacity of trees to contribute as NbS
73 to environmental issues depends on considering this ecological context alongside socio-political contexts
74 (Griscom et al. 2020). Furthermore, tree-planting initiatives can lead to undesirable outcomes and come at
75 great social and environmental costs, e.g. rapidly growing trees can result in limited water availability and
76 agriculture can be displaced, spurring deforestation in other areas (Cao et al., 2009; Holl and Brancalion, 2020).
77 The promotion of trees as a win-win solution could also be used as justification to override socio-economic
78 rights, such as land rights of Indigenous and local communities (Griscom et al. 2020).

79 The objective of this study is to deconstruct the narrative of tree promotion as universal NbS, and to offer
80 nuanced alternatives to consider. We bring together knowledge and arguments from a wide variety of fields
81 such as ecology, political ecology, anthropology and remote sensing to 1) understand this appeal for trees as a
82 one-size-fits-all NbS; and 2) offer alternative narratives, highlighting how the context in which tree promoting
83 initiatives take place matters, and discuss the potential for other biomes, beyond closed forests, to be used as
84 NbS. In doing so, we do not object to the promotion of tree promotion altogether, but aim to deconstruct tree
85 planting as a one-size-fits-all solution to environmental problems and offer alternatives to addressing global
86 environmental crises.

87 88 **2. The appeal of trees as a one-size-fits-all nature-based solution**

89
90 Trees and tree planting in particulars have been emphasized as a general and universal solution to
91 environmental problems, but how did this simplified narrative come to dominate the NbS discourse? In this
92 section, we explore how the indiscriminate promotion of trees reveals a misrepresentation of the diversity
93 amongst stakeholders and perspectives involved in tree planting (Evans, 2009). We first explore the appeal of
94 trees as a universal symbol to solve climate change and biodiversity loss. We then provide more detail on how
95 different stakeholders have adopted these symbols, and how tree planting becomes understood and negotiated
96 within a science-policy interface. Finally, we describe how global forest models are reality-making, allowing
97 trees to be imagined as generic and discrete individuals, together comprising a ‘global forest’.

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2.1 *The symbolism of trees*

As a human-focused solution, trees are seemingly easy to control and measure, and therefore appealing to progress-driven initiatives, allowing stakeholders to actively participate and ‘success’ to be reported. However, the success of tree-planting initiatives for instance are rarely publicly reported in terms of sapling survival rates or maturation percentages. Instead, success is often reported as the number of trees initially planted, benefitting from being fast, easily communicated, and most importantly, visible to wider stakeholders and the public¹. Indiscriminate tree planting narratives generate easily understandable public benefits, crafting trees into hopeful environmental symbols, regardless of native/non-native classifications of planted species (Evans 2009). These shared symbolic generalisations of tree planting can further reinforce group commitment to the tree planting as a panacea paradigm (Wiersum, 1999). Symbols do not hold meaning in itself, but the meaning of a symbol is shaped by those that use it, which makes it possible for a commonly accepted symbol to capture a wide diversity of meanings. This allows users to share the symbol of trees as NbS, while each holding on to their own meaning and motives (Cohen, 1985).

Trees and forests share a long history of symbolism across cultures, which partly explains their attractiveness as NbS. Trees have presence in myth and folklore, sacrosanctity in religion and represent powerful commodities in times of war (Konijnendijk, 2008; Wiersum, 1999). Today, forests are still considered in such symbolic terms, as places of inspiration, meditation and retreat (Konijnendijk, 2017). The understood ‘holiness’ and importance of trees, therefore, is an important reason as to why the story of trees is so attractive. Stemming from the Enlightenment, Western tree symbolism and sanctification can be understood in relation to knowledge-producing entities of the world, creating a universal ‘Nature’ through generalising and scientific unification practices that work on a global systems scale (Tsing 2005). By recognizing the intertwined and irregular development of tree symbolism in various historic, cultural, economic and technological contexts and scales, we can place tree planting and protection into an inclusive narrative, reflective of the diversity of stakeholders and meanings they assign to trees.

2.2 *How tree planting became part of global governance discourse*

While there are records of tree planting occurring as early as ca. 10,000 years ago (Hauer et al., 2008), around 3000 years ago China is known to become the world leader in tree planting, and to be the first nation to appoint a specialized service in charge of forest preservation and reforestation (Evans 2009; Konijnendijk

¹ Some examples: <https://www.bbc.com/news/uk-scotland-north-east-orkney-shetland-51265370>, <https://www.worldwildlife.org/initiatives/reforestation-grants>, <https://www.edinburghairport.com/about-us/media-centre/press-releases/2009/03/04/edinburgh-airport-helps-local-schools-to-do-their-bit-for-the-environment>

2017). Over time and across regions of Earth, the stakeholders and motives behind the dominant tree planting narratives have varied. Yet, in the history of tree planting as a global discourse, the worldwide exploitation and devastation caused by European colonial powers, followed by the industrial scale of tree plantations in the last century, have been of driving influence (Wiersum 1999). In Europe, tree planting was mainly initiated and controlled by professional foresters and governing bodies (Cernea, 1992). In this tradition, trees are considered as crops, or solutions to environmental degradation associated with resource extraction, e.g. reduce soil erosion and climate regulation (Wiersum 1999). The establishment of this formal ‘scientific’ forestry sectors and their associated silviculture practices in Europe coincided with the global expansion of European rule over the last few centuries (Fernow, 1911; Agnoletti et al. 2000). As such, industrial extraction and tree restoration activities have a historical linkage in state-making projects (Tsing, 2005). It is pointed out that this is also the time the narrative of tree planting as a panacea was widely embraced and started to be used in biopolitics (Davis and Robbins, 2018). After the Second World War, which led to the destruction of tree plantations around the world, a combined effect of increased international institutionalization, decolonisation and restoration resulted in tree planting on large scales (Evans, 2009; Stilgenbauer and McBride, 2010). Even in post-colonial independence colonial legacies have remained to influence current day forestry sectors and tree planting initiatives across the world (Davis and Robbins, 2018; Devine and Baca, 2020; Enuoh and Bisong, 2015; Sivaramakrishnan, 1995).

Urbanisation in the last centuries has increased societal pressures on forest management, giving rise to a focus on valuing tree planting as a form of social and environmental public good, in particular near urban areas (Konijnendijk 2000). Both the root causes of deforestation, and tree planting as a solution to tree loss and climatic changes, subsequently ‘leaked’ outside of the realms of forestry (Cernea 1992). This has resulted in an evolution within forestry practices towards social forestry that is people-centred instead of forest-centred (Wiersum 1999). Different groups involved in the promotion of tree planting attach different cognitive beliefs and normative values to trees (Buijs, 2009), resulting in different tree planting goals and strategies (Evans 2009). In recent years, the stakeholder group involved in tree planting has become even more diverse. Governance has shifted from national governments to supra-national (e.g. EU) and regional levels, and to markets and civil societies. This has resulted in a plurality of stakeholders involved in nature management, each with their own values and actions (Keulartz et al., 2004; Pasgaard and Mertz, 2016). Signs of the increase of non-state actors’ involvement in forest management can be found across continents. Previous state dominance led to forests to be considered as ‘political forests’, emphasising that forest are never neutral, but continuously co-produced through power dynamics such as territorialisation, knowledge claims or even violence (Peluso and Vandergeest, 2020, 2011). However, the global environmental governance resulting from the shift in actors can be described as ‘green neoliberalism’, as it is characterised by a redefinition of political forest as part of market-based solutions to environmental crises (Devine and Baca, 2020).

178 Over the last decade, the participation of citizens in global environmental governance has increased, which has
179 led to the development of different types of civic environmentalism (Bäckstrand and Lövbrand, 2006). Some
180 movements are mainly focused on speeding up environmental action with, for example, tree planting
181 initiatives, while others desire change in power dynamics and aim for both a more eco-centric and just world
182 (Bäckstrand & Lövbrand 2006). These changes of focus and strategies, promoting people and planet rather
183 than production, have reshaped the common perceptions of trees. The tree has become a symbol of improved
184 social well-being and climate action. This narrative enables a degree of social power to be gained by those
185 involved in planting initiatives, and those benefiting from the planted trees, especially in urban areas
186 (Konijnendijk 2017). Various actors have adapted this discourse, from politicians (see below) and companies
187 (e.g. airport CO₂ offsetting schemes) to scientists (Newton et al., 2016) and the media². Tree planting is
188 considered as a positive contribution to those with vulnerable livelihoods, and international donor communities
189 promote the planting of trees as a means towards climate change resilience (Etongo et al., 2015). However,
190 despite an increased participation of non-state actors in forestry and forest planting and protection initiatives,
191 community-based programmes do not necessarily provide equal social outcomes (Lund, 2015).

192 Recently, many recent global initiatives have demonstrated strong political will for achieving ambitious targets
193 promoting trees for the sake of climate change mitigation and/or resilience, and/or to counter biodiversity loss.
194 Most notable of these are (i) the Reduced Emissions from Deforestation and Degradation (REDD+) led by the
195 UN and the World Bank aiming to reduce tropical deforestation by creating financial incentives through carbon
196 trading (UN-REDD 2018); (ii) the Bonn Challenge — launched by the International Union for Conservation
197 of Nature (IUCN) and Germany in 2011 and currently involving 56 nations with a global objective of restoring
198 150 million hectares of deforested and degraded land by 2020 and 350 million hectares by 2030
199 (<https://www.bonnchallenge.org/>); (iii) the 2014 New York Declaration on Forests, which pledges to halve
200 deforestation by 2020 and end it by 2030 (<http://forestdeclaration.org/>); (vi) and the Trillion Trees Partnership
201 – a 25-year initiative to restore one trillion trees by 2050 (<https://www.trilliontrees.org/>). The financial
202 rationale for participating in such tree promotion is unmistakable: According to the Organisation for Economic
203 Co-operation and Development (OECD), restoring 46% of the world's degraded forests could provide up to
204 US\$30 in monetary benefits for every dollar spent (World Economic Forum 2020). Besides tree promotion in
205 large-scale public initiatives, private projects promoting trees have proliferated, driven by a combination of
206 consumer demands, environmental stewardship, legal regulations and green branding benefits. Additionally,
207 initiatives based on tree planting tend to gather strong public support. A campaign launched by social media

² Exemplified with a news article headline stating how some Danish political parties '[...] will buy out farmland and plant forest', but in the article itself, the word 'forest' is only mentioned once by one of the politicians.
<https://www.dr.dk/nyheder/politik/stoettepartier-med-krav-til-finansloven-vil-koebe-landmaends-marker-og-plante-skov>

208 influencers in partnership with the non-profit organization Arbor Day Foundation illustrates this positive
209 attitude of the public towards tree planting. The campaign gathered over 800,000 supporters and raised over
210 \$20 million in less than two months to plant 20 million trees around the world (<https://teamtrees.org/>).

211 *2.3 Tree planting dominance in the science-policy interface*

212 Environmental narratives that play a dominant role in shaping societal debates, such as the climate-change
213 policy discourse, are influenced by scientific expertise, but also by their societal and environmental context
214 (Wesselink et al., 2013). Scientists can influence political debates by supplying knowledge, bridging between
215 knowledge producers and users, or facilitating an integration of knowledge production and use (Turnhout et
216 al., 2013). These interactions between science and policy result in knowledge production, decision-making and
217 implementation, which are not linear processes but dynamic co-productions, with unclear boundaries between
218 the two realms (Lövbrand, 2007; Wesselink et al., 2013). Furthermore, with the rise of interface organisations
219 like tree planting NGOs that engage, exchange, collaborate, explain and reward between both sides of the
220 science-policy nexus, an increased flow of scientific knowledge and environmental policy awareness enters
221 into society at large (Osmond et al., 2010). How experts, journalists, civil society organisations and policy
222 makers frame environmental-anthropogenic complexities such as climate change, and their reaction to these,
223 is crucial in the shaping and success of responses to climate change (Dewulf, 2013). If climate change is
224 consistently framed as a technological challenge or as a ‘wicked problem of governance’, this also influences
225 the type of response and adaptation strategies (Dewulf, 2013; Li, 2007). Once dominant, discourses can
226 suppress alternative knowledge claims and policy discourses and their implementation (Wesselink et al. 2013).
227 For example, promoting trees as part of such discourse could divert attention away from behavioural change,
228 e.g. reduced consumption of fossil fuels (Becken, 2004). Planting then becomes a quick fix (relatively
229 speaking), which is convenient to visualize and comprehend, as argued in the following.

230 *2.4 The representation of trees in remote sensing-based global forest models*

231 Global forest models based on satellite remote sensing (SRS) near real-time images have become indispensable
232 in environmental research/monitoring by revealing otherwise invisible narratives of expansive and long-term
233 forest transitions (Tabor & Hewson, 2018). However, the political ecology of these models and their vitality
234 in shaping environmental discourse and symbolism deserves attention (Bennett 2010). Dominant earth system
235 models in general hold strong social shaping power due to their discursive authority and centrality within the
236 science-policy interface (Peterson 2000; Edwards 2010; Hulme 2013). Just as global climate models are
237 central in making global climate a knowable entity, global forest models make forests into a global, knowable
238 entity- rather than forests as local, or regional systems at best. Similar to other earth systems models, global
239 forest models capture core interlocking elements of what a globally scaled forest ‘is’, transforming forests into
240 a knowable ‘whole’ by smoothing out data through an overarching reference frame provided by the model
241 (Edwards 2000). For an SRS-based model to assemble forests into a global ‘whole’, a simplistic definition of

242 what a forest 'is' is epistemically required for stitching together satellite images into a 'global forest'. Once
243 the model enters a digital interface, however, it can be 'credited with the irrefutability of unmediated
244 information'- as environmental historian Richard Hamblyn (2009: 232) writes on graphic representations of
245 climate models. In other words, the model's ability to illustrate a 'global forest' becomes a 'found' object,
246 rather than "made" artefact, which holds the capacity to underpin negligent tree-planting decisions (Tufte
247 1983).

248 Although many SRS-based global forest models exist, the majority emphasize deforestation and forest
249 degradation, while the inclusion of functional characteristics or global, long-term forest transition and
250 restoration - such as spontaneous regrowth or ecologically 'rewilded' - have remained minimal (Chiarucci and
251 Piovesan, 2020). One of the most popularly used, and publicly accessible, SRS-based global forest models is
252 Global Forest Watch (GFW) (Hansen et al., 2013). GFW provides an annual estimation of global tree-cover
253 changes at a spatial resolution of 30m based on long-term observations of Landsat satellite data since 2000.
254 To model global tree-coverage, GFW uses the spectral reflectance signatures of $\geq 5\text{m}$ aboveground biomass.
255 While accurate (Zhang et al., 2020), ecosystem heterogeneity that falls outside of GFW's algorithm — where
256 forests are defined as closed tree crown-cover vegetation $\geq 5\text{m}$ - is flattened into a forest/no forest binary.
257 Savannah systems, for example, are challenging to study via SRS due to the complex relationship between
258 trees and grasses in these biomes, forming a scattered distribution of woody vegetation (Zhang et al., 2019).
259 GFW's algorithmic binary holds limitations when detecting human-planted forests (Tropek et al., 2014),
260 although improvements have been made (Petersen et al., 2016). As a result, GFW's capabilities of detecting
261 coarse forest-change may require supplementary remote sensing products to assess regional ecological
262 complexity. For example, to assess carbon sequestration patterns of dynamic multi-use sub-tropical forests in
263 southern China, Tong et al., (2020) provides a comparison of GFW with the Chinese high resolution satellite
264 data (2m), and a more advanced classification system on different forest types that includes both planted and
265 natural regrowth forests. Through this comparison, Tong et al. (2020) were able to show variations in
266 aboveground biomass and forest dynamics, complicating simplistic forest definitions by providing
267 alternative classifications for what a forest 'is'.

268 GFW is undeniably a valuable and versatile tool: by simplifying forests, forests can be globally articulated and
269 integrated into predictive models, such as climate or habitat suitability, allowing for forests as a global entity
270 to participate in what sociologist Fine (2007) calls 'future work'. However, with a simplified ontology for what
271 a forest 'is', a tree is also able to be transformed into a scalable, a contextual and autonomous unit of biomass,
272 epistemically nestled within a climate mitigating, and 'Nature-making', 'global forest'. For example, by
273 merging GFW with other land-cover layers, Bastin et al. (2019) establishes a global tree restoration potential
274 which emphasizes tree-cover rather than contextualized forests or other nature-types, such as grassland,
275 woodland and savannah systems into estimates of a forest restoration potential and carbon storage (Veldman

et al. 2019). GFW's dominance within a web of integrated models enlists it as both an authoritative model for implementing tree-promoting initiatives, such as REDD+, and as an absolving advocate for companies economically invested in plantation forests, such as Unilever collaborating with GFW (Tabor & Hewson 2018; Hume 2014). While SRS-based global forest models are essential for establishing strong truth-claims, they have also become a durable technological component within a global knowledge infrastructure that has reinforced a bias towards negligent tree-planting in global governance strategies due to the epistemic limitations embedded into these models and their social shaping power going unrecognized. Going forward, a greater attention toward the limitations of such models is needed, as they reinforce particular types of realities. Supplementary products to express regional contexts and their complexities need to be developed and used alongside dominant models that enable and shape global environmental governance strategies, as they may provide a critical vantage point for rethinking indiscriminate NbS.

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288 **3. Context matters**

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In order to achieve a wide range of benefits for climate and biodiversity, tree promotion schemes need to consider the broader context in terms of 1) historical context and the appropriate baseline to use as a reference point to define targets; 2) the ecological context in terms of species composition (*what*), the environmental conditions (*where*), and the type of management (*how*) required to ensure the long-term success of initiatives; and 3) the socio-political context in which the decision-making process is situated (*why* and *who*).

295 ***3.1 Historical context: Shifting baselines in tree planting***

Despite the recent surge in media attention and initiatives, planting trees is by no means unique to our time (Evans 2009). The long history of human impact on forest composition complicates the selection of a reference point to guide the choice of restoration targets and tree planting objectives. Most biodiversity monitoring schemes do not go further back than the end of last century (Mihoub et al., 2017), but failing to integrate the long-term dynamics that gave rise to contemporary landscapes risks misunderstanding the complexity of social and environmental interactions that shaped them (Schweiger et al., 2020). Humans have influenced most ecosystems to some degree, through a long history of land-use and management, to the extent that human activities have become intricately intertwined with natural processes and vegetation development (Szabó, 2010). Just as individuals perceive their own personal experience as normal, the reference state for a natural system progressively shifts over consecutive human generations. The practical implications of this case of collective amnesia – what Daniel Pauly called “the shifting baseline syndrome” (Pauly, 1995) – are management strategies and policy decisions that ignore historical states and processes, thus leading to a narrow universe of potential management outcomes and actions. Reconstructing baselines, however challenging, is

309 thus a critical step towards a better understanding of contemporary landscapes and of the realm of possibilities
310 for future management of trees and beyond.

311 The interplay between humans and the environment over millennia shaped multifaceted socio-ecological
312 systems, making the choice of an appropriate reference point for forest management an arduous task. However,
313 even if former natural processes cannot be completely recovered, decision-makers must be informed about
314 these ecological legacies. Grounding decisions for restoration in a deep-time ecological context will help us
315 better understand the requirements and potentials of extant species (given their deep evolutionary histories),
316 the factors maintaining biodiversity in the long-term, ecological dynamics in the absence of human influence,
317 and the legacies of anthropogenic impact (Svenning, 2020; Swanson et al., 2021). Understanding pre-human
318 reference processes could guide us towards more ambitious restoration objectives and overall promote higher
319 biodiversity and higher resilience to climate change, although it might also conflict with forest management
320 objectives, feasibility and societal acceptance (Svenning 2020, Popejoy et al. 2018). Further, the past is also
321 rich with situated cases from a wide range of socio-ecological contexts and ontological practices related to tree
322 planting and forest management. These form as many empirical examples from which to draw lessons on
323 socio-ecological dynamics, understand drivers of change and explore opportunities for adaptation (Swanson
324 et al., 2021). In box 1, we use one of these examples, the Landes forest in France, to briefly illustrate how a
325 long-term perspective may challenge our perception of what is natural or desirable for tree planting in a
326 particular area.

327 With this, we do not aim to provide recommendations for which baseline should be used to guide forest
328 management strategies. Ultimately, the choice of a baseline as a target for restoration is a societal decision and
329 should be case specific. But combining natural and social sciences with this historical perspective can be a
330 powerful tool to broaden perspectives for what is possible, help avoid repeating past errors and envision
331 possible futures.

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Box 1. Shifting baselines and forested landscapes: The Landes forest in France

In Europe, the reversal from forest decline to expansion alongside urban development creates a useful case study to explore the impact of shifting baselines in contemporary tree planting initiatives. Land claims for agriculture, resulting in widespread deforestation since the Neolithic age, gave way to reforestation in Europe during the middle ages and onwards. These reforestation initiatives focused on restoring exploited areas and changing species composition of forests, e.g. from beech to spruce forests (Evans 2009), primarily for economic purposes. Since two centuries ago, this focus expanded to include afforestation of previously bare lands and coniferous plantation forestry became the norm (Kenk and Guehne, 2001).

The Landes forest in southwestern France illustrates this historical trajectory well. The area was planted with maritime pines *Pinus pinaster* over thousands of hectares ca. 175 years ago to provide regional economic development, by converting sparsely inhabited agro-pastoral heathlands ('landes' means moor in French) into a forest exploited for wood and pine resin harvesting. This process involved the large-scale drainage of wetlands and resulted in the loss of unique traditional practices (the '*berger des Landes*', walking on stilts, is a classical depiction of this lost pastoralist tradition). Today, this area is dominated by dense pine plantations in what has become the biggest artificial forest in Western Europe (ca. 1.2 million hectares) and serves recreational objectives due to its aesthetics and cultural values (Bouisset and Degrémont, 2015), but remains low in biodiversity. Restoring heathlands in this area could thus be seen as a promising strategy to restore ecosystems to their natural state and promote higher biodiversity and resilience to climate change. However, paleo-ecological studies reveal that the heathland does not represent the 'natural' baseline for this system either. Pollen reconstruction suggests that throughout the early Holocene (from ca. 8000 years ago), the landscape was dominated by open woodlands (Faure and Galop, 2011) and that heathland only became dominant towards the middle-ages after several millennia of progressive deforestation initiated at the end of the Neolithic (ca. 5500 years ago). In this context, the choice of one temporal baselines as a reference point for decision-making is challenging and will dramatically affect the realm of possibilities for contemporary forest management (Figure 1). There are benefits and challenges, and certainly limits in what is societally acceptable and ecologically possible, to every scenario. Nonetheless, gaining an understanding of these long-term socio-ecological legacies is critical to determine what is possible and desirable today and in the future.

Figure 1. Fictional example illustrating the impact of shifting baselines for forest management decisions. The type of data available to reconstruct historical baselines varies as one goes back in time, from ecological surveys and Traditional Ecological Knowledge (TEK) (Huntington, 2000) to historical and industrial (e.g. forestry) sources, fossil and pollen records and molecular data (ancient and modern DNA), illustrating the need for trans-disciplinary approaches to overcome the shifting baseline syndrome.

3.2 Ecological context: what, where, how to plant?

Following the decision of which is a desirable target for forest restoration, an important starting point is to consider to what extent – if any – trees need to be planted. Natural regeneration can often be effective in restoring forests and woodlands for NbS, helping to promote higher taxonomic and genetic biodiversity (including of native tree species) as well as structural complexity, which is strongly related to biodiversity (Chazdon and Guariguata, 2016). However, some species are limited in their ability for spontaneous regeneration, e.g., due to large seeds adapted for dispersal by now-extinct megafauna, overall rarity or local extirpation due to overuse by humans or lack of processes to facilitate germination. In such cases, it can be relevant to combine natural regeneration with planting. Secondly, old-growth forests sustain unique

400 biodiversity (Watson et al., 2018) and are more effective in regulating the climate, e.g. because large trees
401 sequester more carbon than small trees despite lower per unit carbon sequestration efficiency (Musavi et al.,
402 2017; Poorter et al., 2015; Watson et al., 2018). Replacing old growth forest with young, faster-growing trees
403 will always reduce the amount of biospheric carbon stored per unit land area, at least over a 100-200 year
404 period (Körner, 2000; Lewis et al., 2019). Slow-growing trees with longer lifespans will contribute more to
405 carbon storage than fast tree growth followed by harvest and carbon release, as the latter contributes no long-
406 term carbon benefit (Körner, 2017).

407 Tree-planting initiatives as a NbS for climate change and the biodiversity crisis should focus on areas where
408 co-benefits for carbon storage and biodiversity can be maximized, which requires an understanding of the
409 patterns of environmental and climatic characteristics driving these two critical aspects (Soto-Navarro et al.,
410 2020). Importantly, tree stands with high species richness of mainly native species and high structural
411 heterogeneity are more likely to be resilient to stresses from climate change or introduced tree pests, and will
412 generally have higher productivity (Morin et al., 2011) and biodiversity (Felton et al., 2020). In contrast,
413 species-poor and structurally uniform tree plantations often have negative effects on biodiversity (Bremer and
414 Farley, 2010) and lower carbon sequestration capacities (Li et al., 2019) and in general lower ecosystem
415 services (Gamfeldt et al., 2013). They are also unlikely to be robust to site-specific disturbance regimes and
416 global change stresses. For example, diversity and resilience of above ground carbon stocks within fire-prone
417 natural forests is supported by fire-response traits facilitating fire survival and allowing rapid post-fire
418 regeneration (Clarke et al., 2015; Gordon et al., 2018; Hammill et al., 2016). Therefore, plantations of non-
419 native trees that have not coevolved with fire, and hence do not possess fire-response traits, are unlikely to
420 provide long-term carbon sequestration gains in fire-prone regions.

421 Carbon sequestration per unit area of forest depends on climatic processes that impact rates of carbon gain
422 through photosynthesis and carbon loss via plant and microbial respiration (Anderson-Teixeira et al., 2011;
423 Keith et al., 2009; Melillo et al., 2017). Aboveground carbon storage is typically highest in (moist) cool-
424 temperate forests where moderate temperature and precipitation favour plant growth over decomposition
425 (Keith et al., 2009; Liu et al., 2014). Conversely, aboveground carbon sequestration is tempered in cooler
426 boreal forests where low temperatures reduce photosynthesis and plant growth, and tropical forests where
427 warm and wet conditions promote decomposition (Keith et al. 2009; Liu et al. 2014a). Overlapping areas of
428 high carbon storage potential with areas that have high potential for biodiversity conservation in forest
429 ecosystems, makes it possible to identify areas where tree planting could – taking other context variables into
430 account – achieve these joint goals (Soto-Navarro et al. 2020). With growing availability of high-resolution
431 maps of carbon stocks and biodiversity distribution, spatially explicit tree planting planning can increasingly
432 be implemented for the co-benefit of carbon storage and biodiversity (Soto-Navarro et al. 2020).

Anthropogenic climate change is intensifying and expected to increase pressure on forests over the next decades and beyond, due to drought, heat stress or increased fire risk (Paquette et al. 2018). Therefore, it is important that newly forested areas are resilient to these stresses. Tree species richness is important to buffer against loss of ecosystem productivity and biodiversity from climatic stresses and/or the rising prevalence of introduced tree pests and pathogens (Fichtner et al., 2020; Grossiord, 2019; Grossman et al., 2018; Huang et al., 2018; Jactel et al., 2017). Promoting such resilient ecosystems may be achieved by innovative management strategies such as rewilding (Svenning, 2020), which aims to restore ecological processes that promote self-regulation of ecosystem functions, natural disturbance regimes, and connectivity (Perino et al., 2019). Restoring these factors and processes also ensures that restoration efforts benefit the many species that depend on open- and semi-open habitats (e.g. glades within forests), coarse woody debris and other aspects of ecosystem structure that simple tree planting schemes may overlook (Schweiger and Svenning, 2019).

3.3 Socio-political context

The *what*, *where* and *how* of tree planting addressed above interrelate with the socio-political (*who* and *why*) and the long-term biogeographical context in which landscapes and ecosystems are formed. Political and historical perspectives also need to be included to set appropriate reference points. From a decision-making perspective for instance, the persuasive end goal of climate change mitigation sometimes outweighs the means to get there, as its power and urgency calls for fast actions to reduce deforestation and enhance carbon uptake in a way that seem to override scientific scrutiny (cf. Berling and Bueger, 2017) and limit a nuanced discussion on exactly *where* and *how* to promote trees as carbon sinks.

Under the climate action umbrella, a particular set of economic incentives and mechanisms to protect and plant trees has been on the rise for several decades (Gómez-Baggethun and Ruiz-Pérez, 2011), and provides an example and possible explanation for why more nuanced ecological criteria for promoting trees as a NbS are not always considered. Initiatives relying on Payment for Ecosystem Services (PES) captures many tree planting and protection programs, such as global climate action projects based on carbon savings from reduced deforestation and enhancement of forest carbon stocks (REDD+). Such PES-like schemes rest on neo-liberal thinking and market-based instruments, illustrating a dominance of (environmental) economists in shaping many large-scale nature conservation programs (Pasgaard et al., 2017). In the slipstream of their dominance, PES-like projects are often criticized for being apolitical and unjust (Fairhead et al., 2012; Milne and Adams, 2012; Van Hecken and Bastiaensen, 2010). Some of this discussion revolves around the geographical location of projects (e.g. Balooni and Lund, 2014) and the actors involved (e.g. Sanders et al., 2017), which are critical when it comes to identifying locations for tree planting and protection. The actual project site selection often depends on what is most feasible and desirable for actors implementing the policies, taking into account their individual agendas and previous engagements rather than ecological criteria (Pasgaard and Mertz, 2016).

Several studies have shown that climate action initiatives through tropical forest protection not only may overrule democratic considerations in the name of carbon reductions (e.g. Fairhead et al. 2012), but also involve considerable biodiversity trade-offs (Phelps et al., 2012). In other words, the actual promotion of trees as a NbS tends to be prioritized in places where it fits the branding and existing activities of the climate project investors and implementers (cf. Mosse, 2005; Goldman, 2005) – and not necessarily the ‘best suited’ locations from an ecological viewpoint in terms of carbon reductions or biodiversity (Pasgaard and Mertz 2016).

4. Beyond closed forests: valuing other biomes as NbS

The current narrative of trees and tree planting promotes forest as the ultimate NbS for environmental and biodiversity challenges (Griscom et al., 2020). However, forest structures contain a gradient of tree cover densities, and open spaces are considered inherent to forests and play important roles in forest biodiversity and vegetation dynamics (Muscolo et al., 2014). Further, while forests harbour the majority of Earth’s terrestrial biodiversity (Jones et al., 2018; Kreft and Jetz, 2007), non-forest biomes support unique biodiversity and functions, including carbon sequestration. This section provides a brief ecological background to non-forest biomes, often referred to as open or semi-open vegetation, and will demonstrate why open vegetation plays a key role in global conservation of biodiversity. We also address why open vegetation is not necessarily inferior to closed forest when it comes to sequestering carbon or cooling the Earth system in other ways.

4.1 History and biodiversity of other biomes

Open or semi-open vegetation does not imply the complete absence of trees. Rather, it implies an absence of large contiguous areas with closed canopy cover. The naming of biomes or vegetation types with less than 100% tree cover has been inconsistent, and subject to cultural customs and historical conventions (Higgins et al., 2016; Kumar et al., 2020). Common names include ‘forest’, ‘savanna’, ‘woodland’ and ‘shrubland’, with or without further qualifiers such as ‘open’ and ‘dense’. However, tree cover alone is not sufficient to categorise landscapes on a forest /non-forest gradient, and other aspects of vegetation structure and plant traits need to be considered, especially the presence and abundance of grasses. For example, in the (sub-)tropics the presence of a more-or-less continuous cover of C₄ grasses is a reliable indicator that the vegetation is not a forest, even if tree canopy cover is > 80% (Ratnam et al., 2011).

C₄ grasslands spread globally during the late Miocene and Pliocene (3 to 8 Ma) and were accompanied by a surge in grass-fuelled fires, especially in the seasonally dry subtropics, i.e. today’s vast savannahs of Africa, South America, India and Australia (Bond and Keeley, 2005; Lehmann et al., 2011). These novel grassy and flammable environments triggered adaptations and diversification in other taxa, including a spectacular diversification of the bovid family, including bison, gazelles, wildebeest, and sheep (Charles-Dominique et al.,

2016). Dominant tree species in open grassy vegetation typically have adaptations to resist, avoid or cope with fire and large mammal herbivores, the two main consumers of live plant biomass (Bond & Keeley 2005). Tropical and subtropical savannahs, especially in Africa where a largely grass-dependent megafauna has mostly escaped the late-Quaternary extinction wave, clearly illustrate the unique biodiversity that would be lost if trees were planted without considering the ecological context. Many other taxa demonstrate the significance of non-forest vegetation in driving diversification and supporting non-forest biodiversity, also in non-forest ecosystems without C₄ grasses. For example, the falcon family (Falconidae) diversified rapidly with the Miocene expansion of C₄-grasslands (Fuchs et al., 2015) and the majority of European butterflies depend on open ecosystems or semi-open spaces within woodlands (Streitberger et al., 2012; van Swaay et al., 2006). The seeds or seed capsules in Mediterranean shrublands such as the Fynbos require exposure to fire and/or smoke to open and germinate; a clear indication of a long fire history, which is incompatible with closed-canopy forest (Lamont et al., 1991; Rundel et al., 2016). In summary, non-forest ecosystems have produced and continue to maintain taxa that are fundamentally incompatible with closed-canopy forests. We discuss below how these ecosystems play an important role in climate regulation through carbon sequestration and other radiative forcings.

4.2 *Climate regulation by other types of ecosystems*

Carbon sequestration

As grasses and savannah trees have less (woody) biomass than typical forest trees, they store less above-ground carbon per unit area per unit time than a typical closed forest. However, like closed forests, savanna ecosystems also sequester and store carbon, notably below-ground. As such, they are a major contributor to global carbon dynamics and Earth's energy balance (Poulter et al., 2014). Furthermore, recent studies show that soil carbon storage in tropical savannahs is higher in savannahs with fewer woody plants, suggesting that grasses are more effective at storing carbon below ground in the absence of trees (Wigley et al., 2020). Importantly, areas with fewer trees were maintained in that state by native wild herbivores, underlining the importance of ecosystem processes. Similarly, flammable temperate savannahs may have more soil carbon than nearby forests that do not burn (Pellegrini et al., 2020). Ecosystems that are not forest nor grassy are also important for the global energy budget. For example, tundra and associated permafrost are the largest soil carbon sink globally, accounting for approximately 50% of all soil carbon stocks (Tarnocai et al., 2009). Wetlands including peat bogs cover 5–8% of the terrestrial land surface but store 20–30% of Earth's soil carbon (Dargie et al., 2017), even when methane emissions are considered (Mitsch et al., 2013). As for grassy ecosystems, disturbance regulates soil carbon sequestration in both tundra and wetland ecosystems. For example, large herbivore grazing moderates climate-mediated carbon losses in tundra (Ylänne et al., 2020).

Climate trade-offs in tree planting

533 In addition to sequestering and storing carbon, vegetation can warm up or cool down the Earth's surface in
534 other ways. The first important mechanism is the reflectivity to sunlight, albedo: the higher the reflectivity of
535 a type of vegetation, the less heat is absorbed. The albedo is higher for savannah grasses (grey-green) than e.g.
536 tropical forests (dark green) (Bonan, 2016, 2008). Furthermore, most commercial forestry species suitable for
537 semi-arid climates are evergreen (e.g. pines), which means that additional heat gets absorbed during the dry
538 season, when native vegetation tends to be bare or brown (high albedo). This overall higher heat reflection of
539 grassy ecosystems compared to forests helps cool the Earth surface (Bonan, 2016; Lee et al., 2011). Secondly,
540 all plants transpire water into the atmosphere through small pores in the leaf (stomata). Water vapour is also a
541 powerful greenhouse gas and planting trees will thus increase the amount of water vapour in the atmosphere
542 (Swann et al., 2010) as woody vegetation contributes more to evapotranspiration than grasses (Yepez et al.,
543 2003). Besides the carbon storage qualities of trees, forest could consequently increase local temperatures and
544 have unintended side effects on climate warming (Baldocchi and Penuelas, 2019; Rotenberg and Yakir, 2010).
545 The role of trees and other vegetation in climate warming is therefore not one-dimensional, and we need to
546 increase efforts to understand key processes that regulate the climate impacts of closed forest and non-forest
547 ecosystems, including albedo and effects of surface roughness on energy exchange (Bonan 2016).

548

549 Discussion & conclusion

550

551 The aim of this paper is not to object to the promotion of trees. Instead, we aim to explore the origins of tree
552 promotion as the panacea for NbS and to provide alternatives and complementary strategies. To do so, we
553 provided an overview of historical social and ecological factors that need to be considered in order for the
554 promotion of trees to have the desired effects, e.g. mitigate the biodiversity and climate crises. Our main
555 argument is that tree planting has become a generalizable ‘technical’ NbS to address climate change, which
556 overlooks regional contexts and other potential solutions. Without arguing against tree planting or promotion
557 *per se*, its simplified dominance calls for a nuanced approach to global environmental challenges by exploring
558 the limitations and oversights of tree-centered solutions, within appropriate ecological and socioeconomic
559 contexts

560 Tree planting is an attractive solution to environmental issues because it is straightforward and has a shared
561 positive symbolic connotation. The simplistic discourse around tree planting is co-created by the historical
562 meaning of trees, the shift in stakeholders and perspectives involved in tree planting towards environmentalism
563 and the framing of environmental issues as technological challenges or as wicked problems of governance.
564 However, this simplistic framing distances the causes and solutions of environmental issues away from
565 individual, corporate, and regulatory governance responsibilities. Our remote sensing-based examples indicate
566 that the representation of trees in global forest modelling potentially reinforces an overly simplistic definition
567 of trees and forest (section 2.4). The implications of these simplifications influence decision-making processes
568 concerning tree promoting initiatives (section 3.3 and Chapter 2). In order to reflect on the potential of
569 rethinking the current tree planting discourse and be receptive to a more inclusive and diverse perspective on
570 NbS, we therefore need to remain critical of accepted methodologies and be mindful of their limitations.
571 Although global forest models have built an important basis for globally monitoring forest-cover changes, the
572 global image they provide only partially reflects on-the-ground complexities, and therefore should not be used
573 as a standalone authority. The recent arrival of high-resolution satellite data provides diverse coverage and
574 new opportunities to create more nuanced observations that model forests as a global object.

575 Despite the victory of international policy and financial commitments to promote tree planting as a way to
576 address human induced climate issues and the loss of biodiversity, tree planting is not the global panacea. Di
577 Sacco et al. recently gathered evidence from the most recent ecological research to propose ten golden rules to
578 support the delivery of forest restoration approaches that maximizes rates of both carbon sequestration and
579 biodiversity recovery while improving livelihoods (Di Sacco et al., 2021). They argue for forest restoration
580 initiatives to be “*based on sound science, guided by indigenous knowledge and local communities, supported*
581 *by fair governance, and incentivized by long-term funding mechanisms*”. Our paper supports this nuanced
582 narrative, as we notably argue that tree planting and promotion needs to reflect and be in sync with the social

583 and ecological context (Figure 2). More specific ecological criteria regarding which species, and where, how
584 and who to promote trees need to be further taken into account in tree promotion initiatives. Yet, we do not
585 argue to rely on ecological criteria alone, as this would be both unrealistic and undesirable. By selecting areas
586 for tree planting or protection based solely on ecological or climatic criteria, we might risk yet another case of
587 ‘green grabbing’ when those with political power dispossess local communities from their rights (Fairhead et
588 al. 2012). Instead, we strongly argue to always include both ecological and socio-ecological knowledge
589 alongside political and economic considerations, in order to nuance decisions about the selection of species
590 and locations for tree planting or protection (Swanson et al., 2021).

591 Other NbS should also not be excluded from the dialogue. Our discussion in Chapter 3 illustrates three
592 important points: 1) More trees, or greater tree cover replacing open vegetation, does not necessarily mean
593 more carbon sequestration, 2) Disturbances such as fire and herbivores that remove above-ground biomass can
594 increase carbon sequestration relative to undisturbed forests, and 3) Tree planting does not necessarily generate
595 a higher (local) reduction in temperature compared to other types of vegetation. Collectively, these examples
596 highlight that non- (closed) forested ecosystems across a diverse range of landscapes and biomes are crucial
597 in regulating Earth’s carbon budget.

598 Fundamentally, tree planting should aim beyond mere carbon sequestration for climate regulation and focus
599 on socially just initiatives generating biodiverse, self-regulating ecosystems resilient to global change stresses
600 and that consider biodiversity holistically, beyond trees (Veldman et al. 2015; Brancalion & Chazdon 2017).
601 Priority should also be given to other climate solutions such as reduction of fossil fuels and avoiding
602 deforestation (Grantham et al., 2020) and the potential for other natural carbon storage ecosystems, such as
603 wetlands and peatlands, should not be overshadowed by discussions on tree planting. In policies and
604 interventions, NbS should be nuanced by unfolding the context (what, where, how, who) and by embracing
605 and valuing other vegetation types in addition to forests as NbS, and these alternatives must of course also be
606 applied in a context-sensitive manner. Aiming for these ambitious objectives is the way forward to avoid
607 creating unstable systems with ultimately limited or zero benefits for biodiversity and climate, and thereby
608 human societies.

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614 **Figure 2.** Schematic diagram of the road from tree planting as a panacea narrative (left panel) towards a
 615 more nuanced narrative, rooted in the historical, ecological and social-political context (right panel), which
 616 values other ecosystems as nature-based solutions (NbS) and also protects non-closed forest ecosystems and
 617 biodiversity. In order to support this shift, we deconstructed the historical and power dynamics that played a
 618 role in the construction and maintenance of this panacea framework. The power of shared symbolism, shifts
 619 in environmental governance, science-policy-public knowledge and policy co-production and the biases and
 620 simplifications required to construct models to study forest ecosystems need to be acknowledged as part of the
 621 ‘problem’ and ‘solution’ to obtaining a nuanced perspective on tree planting.

622

623

624 Acknowledgments

625 This work is a contribution to the Carlsberg Foundation Semper Ardens project MegaPast2Future (grant no.
 626 CF16-0005 to J.-C.S.), to the VILLUM Investigator project ‘Biodiversity Dynamics in a Changing World’
 627 funded by VILLUM FONDEN (grant no. 16549 to J.-C.S.) and to TerraNova - The European Landscape
 628 Learning Initiative: Past and Future Environments and Energy Regimes shaping Policy Tools (grant 813904)
 629 funded by the European Commission.

630

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