Perspectives in Ecology and Conservation 21 (2023) 25–32

Perspectives in ecology and conservation

Supported by Instituto Tecnológico Vale

www.perspectecolconserv.com

Essays and Perspectives

Optimal references for ecological restoration: the need to protect references in the tropics

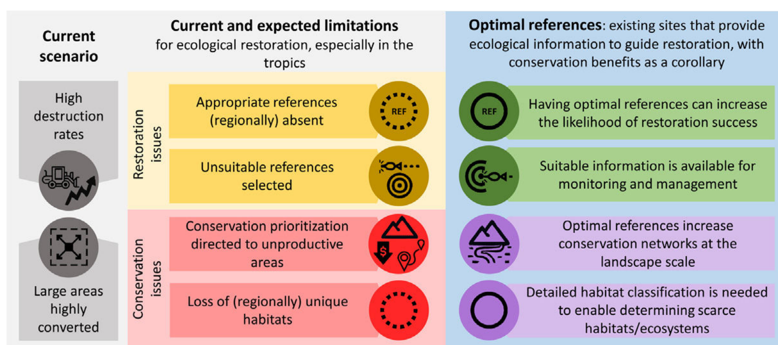
Tiago Shizen Pacheco Toma[a,b,*,1], Gerhard Ernst Overbeck[a,b,c], Milton de Souza Mendonça Jr[a], G.Wilson Fernandes[b,d]

[a] *Programa de Pós-Graduação em Ecologia, Universidade Federal do Rio Grande do Sul (UFRGS), Av. Bento Gonçalves 9500, 91501-970, Porto Alegre, RS, Brazil*
[b] *Knowledge Centre on Biodiversity - Brazil, Belo Horizonte, MG, Brazil*
[c] *Departamento de Botânica, Instituto de Biociências, Universidade Federal do Rio Grande do Sul (UFRGS), Av. Bento Gonçalves 9500, 91501-970, Porto Alegre, RS, Brazil*
[d] *Ecologia Evolutiva & Biodiversidade, Departamento de Genética, Ecologia e Evolução/ICB, Universidade Federal de Minas Gerais (UFMG), Belo Horizonte, MG, Brazil*

HIGHLIGHTS

- References are key to restoration, especially in highly threatened ecosystems.
- Optimal references connect conservation and restoration.
- Small remnants that serve as references can lead to landscape-scale benefits.
- A detailed habitat classification is needed for adequate protection and restoration.
- Ensuring optimal references protection will benefit future restoration initiatives.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 8 March 2022
Accepted 31 January 2023
Available online 14 February 2023

Keywords:
Conservation planning
Environmental policy
Land use planning
Reference ecosystems
Tropical ecology

ABSTRACT

Restoration and conservation are linked by the fact that restoration can help improving, expanding, or connecting protected areas. Here, we argue that conservation can play a critical role for restoration by targeting optimal references, i.e., areas representative of the spectrum of different habitats to be restored. In view of high rates of habitat loss in parallel with recently established ambitious restoration goals, the availability of adequate references is of high importance to restoration. However, not always the best possible references are being used, nor are they prioritized in conservation. We discuss the need for defining, prioritizing, and protecting optimal references as a strategic approach thus we would be better equipped to tackle current and forthcoming challenges in conservation and restoration.

* Corresponding author.
E-mail addresses: tiagoshizen@gmail.com (T.S. Toma), milton.mendonca@ufrgs.br (M.S. Mendonça Jr), gw.fernandes@gmail.com (G. Fernandes).
[1] Present address: Ecologia Evolutiva & Biodiversidade, Departamento de Genética, Ecologia e Evolução/ICB, Universidade Federal de Minas Gerais (UFMG), Belo Horizonte, MG, Brazil.

https://doi.org/10.1016/j.pecon.2023.01.003

Introduction

The recent rise in commitments for the restoration of large areas (e.g., Murcia et al., 2016; Crouzeilles et al., 2019; Fagan et al., 2020) is an attempt to recover part of what has been destroyed, and this recognition of the need for ecological restoration culminated with the designation of this decade (2021–2030) as the UN Decade on Ecosystem Restoration (Cross et al., 2019). Well-planned restoration can contribute to conservation success (Possingham et al., 2015). This is paramount in regions with high levels of conversion that suffer persistent habitat loss (Williams et al., 2020), pushing ecosystems towards risky thresholds of representativeness and connectedness due to fragmentation (Wintle et al., 2019). Often, these regions include small natural remnants, which are valued by the restoration mindset (Young, 2000), but much less by conservation (e.g., Wintle et al., 2019; Mangueira et al., 2021). In addition to maintaining biodiversity, protected areas can serve as relevant references for restoration, especially in a scenario where natural ecosystems are changing rapidly as a result of climate change.

Having appropriate reference ecosystems (i.e., natural or near-natural ecosystems) as a beacon in restoration practice is what distinguishes restoration from other engineering aimed at amending degraded areas (Fig. 1; Balaguer et al., 2014). Still, reference ecosystems have been taken as difficult to find (Higgs et al., 2014) or even forsaken when admitting novel ecosystems (e.g., Hobbs et al., 2009). Considering the use of references as facultative is problematic not only due to the risk of distorting restoration but also as it "opens the door to impunity" when restoration is used as an offset or compensatory measure (Murcia et al., 2014).

In the Global South, restoration and conservation face strong limitations to their full application in achieving pressing goals to avert the global environmental crisis. Limitations include lack of local research, enormous and unknown biodiversity, coarse ecosystem classifications, poorly documented land use history, and high degradation rates. Here, we explore these limitations to argue that restoration should be guided by appropriate references, and that these reference sites should be protected to ensure the possibility of monitoring and evaluation as the site under restoration matures. First, we present an overview on the key role of references in restoration and propose the concept of optimal references. Second, we discuss limitations in conservation planning that can negatively affect restoration and address what could be done to overcome such limitations, especially considering optimal references. Finally, we offer some perspectives and implications of finding and protecting optimal references.

References and their contribution to restoration

The SER Standards (Gann et al., 2019) suggests the use of a reference model, which expands the concept of reference ecosystems to accommodate "predicted changes in environmental conditions" and would preferably be composed of various reference sites. A reference model ideally comprises a dynamic historic component, by accounting for temporal change (Gann et al., 2019); this can be provided by a reference site that is maintained through time and is subjected to internal and external factors acting locally (Balaguer et al., 2014). In other words, an appropriate reference ecosystem is equivalent, close and contemporary to the ecosystem that occurred in the restoration site. We acknowledge the conceptual distinction between reference sites, ecosystems and models as proposed in the SER Standards, and hereafter use references when referring to reference sites: "an extant intact site that has attributes and a successional phase similar to the restoration project site and that is used to inform the reference model".

In practice, finding appropriate reference sites is becoming increasingly difficult in many landscapes (Clewell and Aronson, 2013; Gann et al., 2019), since original ecosystems are progressively being altered (Williams et al., 2020). Hence, roughly three situations may be present in terms of availability of references: (a) references are widespread near the restoration site, which may even hold important characteristics from the original ecosystem (Fig. 2A), (b) at least one reference is regionally present (Fig. 2B), or (c) no references are available (Fig. 2C).

When references are widely available, it is possible to build informed reference models that include information on spatial variation. Additionally, reference sites in closer vicinity to the restoration site may act as propagule sources and contribute to connectivity to the site under restoration, improving the likelihood

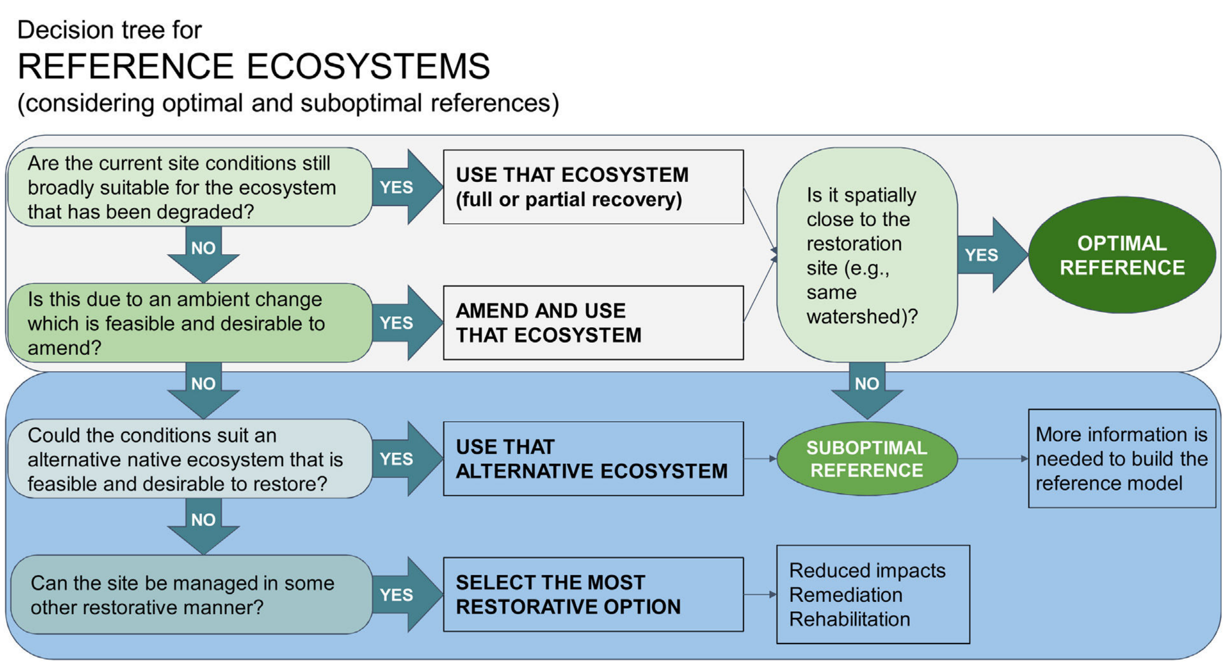


Fig. 1. Decision tree for reference ecosystems indicating which would be considered optimal references (modified from Gann et al., 2019).

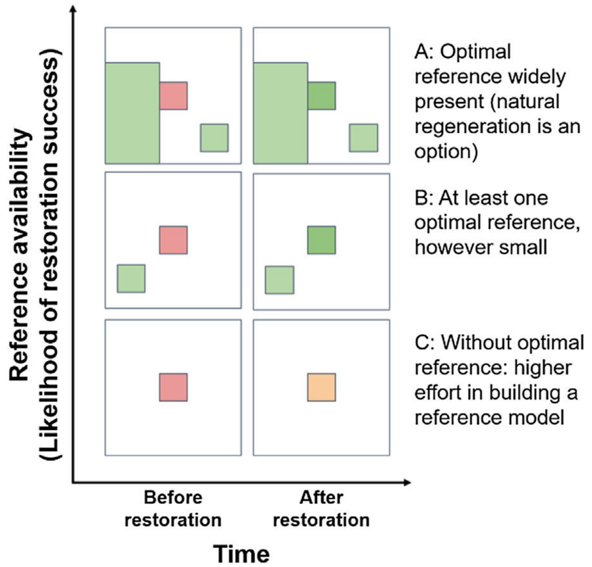


Fig. 2. Importance of reference sites for restoration. The likelihood of restoration success corresponds to reference availability. When optimal references (light green) are widely available, restoration at the restoration site (red) is facilitated and the site can be restored (dark green) (A). When there is at least one optimal reference, however small, restoration is also facilitated and the site can be restored (B). Without an optimal reference, the process of building a reference model is hampered and restoration risks failing (orange) (C).

of success (Fig. 2A and B). In degraded areas that still hold enough elements (e.g., seed banks, vegetation remnant areas) from the original ecosystem or are closely connected to conserved sites, natural regeneration (passive restoration) is possible and may even present better results than after active restoration (Crouzeilles et al., 2017). Situations like these are unfortunately rare in landscapes strongly affected by human use (Arroyo-Rodríguez et al., 2020). Previous experiences of restoration without references were mostly limited to small areas with low degradation levels and relied on practitioners' experience in local natural history who helped planning the project, and extended maintenance period (Clewell and Aronson, 2013).

In highly degraded regions, references are scarce and each reference holds great relative value (Fig. 2B). In the worst cases, degradation levels in restoration sites are so high that references are regionally absent, which demands higher effort in building a reference model (Fig. 2C). In this case, reference models might rely solely on secondary sources of information such as paintings, site descriptions, or even palynological and archeological records (Clewell and Aronson, 2013; Gann et al., 2019). Of concern is that such kind of information and aid is seldom available and can be costly. For regions with important gaps in ecological knowledge, notably the case in the tropics (e.g., Laurance and Edwards, 2011), the use of secondary information includes a high risk of overlooking the still unknown biota. Additionally, the scarcity or absence of references means landscape scale dynamics is impaired and higher maintenance efforts are necessary, which also translates into higher costs. Ultimately, restoration without a reference ecosystem is likely to fail, either structurally or functionally.

It has been suggested that historical references are obsolete (Hobbs et al., 2009). This perspective is related to the novel ecosystems concept (Hobbs et al., 2006), suggesting that new sets of abiotic and biotic components will interact and prevail in ways that will profoundly differ from historical ones. This view has been criticized as being potentially harmful by 'sending conflicted messages to governments worldwide' before appropriate scientific scrutiny (Murcia et al., 2014). Especially for regions characterized by severe limitations for restoration and conservation such as most of the tropics (discussed in the next section), the novel ecosystems concept should be used with caution (Murcia et al., 2014). So far, the existing references actually represent capital sources of information to guide restoration in those regions in order to achieve proper restoration scaling up (Murcia et al., 2016). Such references, instead of being disregarded by being 'increasingly hard to find' (Higgs et al., 2014), should indeed receive special attention in order to be protected.

Box 1. Common issues on selecting reference sites and suggested solutions based on optimal references

Appropriate reference ecosystems are often unavailable, unattainable, or inappropriate, which can hamper the suitability of a reference model. Most common reasons related to issues when building reference models are:

1) Selection procedures could have been unclear and may have led to the selection of sites with contrasting ecological conditions to those of the restoration site (Fig. I–1a);
2) Current environmental condition and/or quality of the sites chosen as references is deficient, e.g., due to inadequate conservation states (Fig. I-2a);
3) There are constraints on the state of the restoration site that could not be removed despite restoration efforts, which means that the restoration reference state cannot be achieved, i.e., goals are unrealistic (Fig. I-3a);
4) Well-conserved sites that can be used as references do not exist anymore, and only sites with limited similarity to the restoration site are available (Fig. I–4a).

These limitations can be overcome: if reference sites were more evenly distributed in space (as to include variability) and close to sites needing restoration (Fig. I-1b), problem 1 can be solved. If reference sites were included in some kind of Protection/Conservation Area (Fig. I-2b), problem 2 can be solved. Problem 3, while also presenting a mismatch between restoration and reference sites, is mostly related to the degradation state of the site to be restored; in these cases, after restorative activities are put into practice (Fig. I-3b), the restoration site could potentially even serve as a source of propagules and thus contribute to restoration at the landscape scale. Problem 4 cannot be solved in highly altered landscapes; however, if a sufficient portion of natural habitat were to be placed under a conservation scheme envisioning future scenarios that include restoration, this problem could be avoided for the future (Fig. I-4b). This makes effective conservation planning a key condition for construction of appropriate restoration models and thus successful restoration in the future.

Optimal references

One way to guarantee that appropriate references are available when needed starts with defining such references preemptively and protect them as an investment for the future. Therefore, we propose the concept of **optimal references** in ecological restoration. Basically, it corresponds to the two initial steps in the decision tree for reference ecosystems suggested by the SER Standards, but we emphasize that ideally the reference should be spatially close to the restoration site (Fig. 1). Optimal references are sites in reasonable states of preservation that are representative of one or more ecosystems occurring in a region, hold native ecological characteristics, and have only eventually undergone some, and usually minor, changes in composition or structure due to land use and other external factors (Fig. 2A and B). Of course, the decision whether a site is in fact an optimal and appropriate reference can only be made

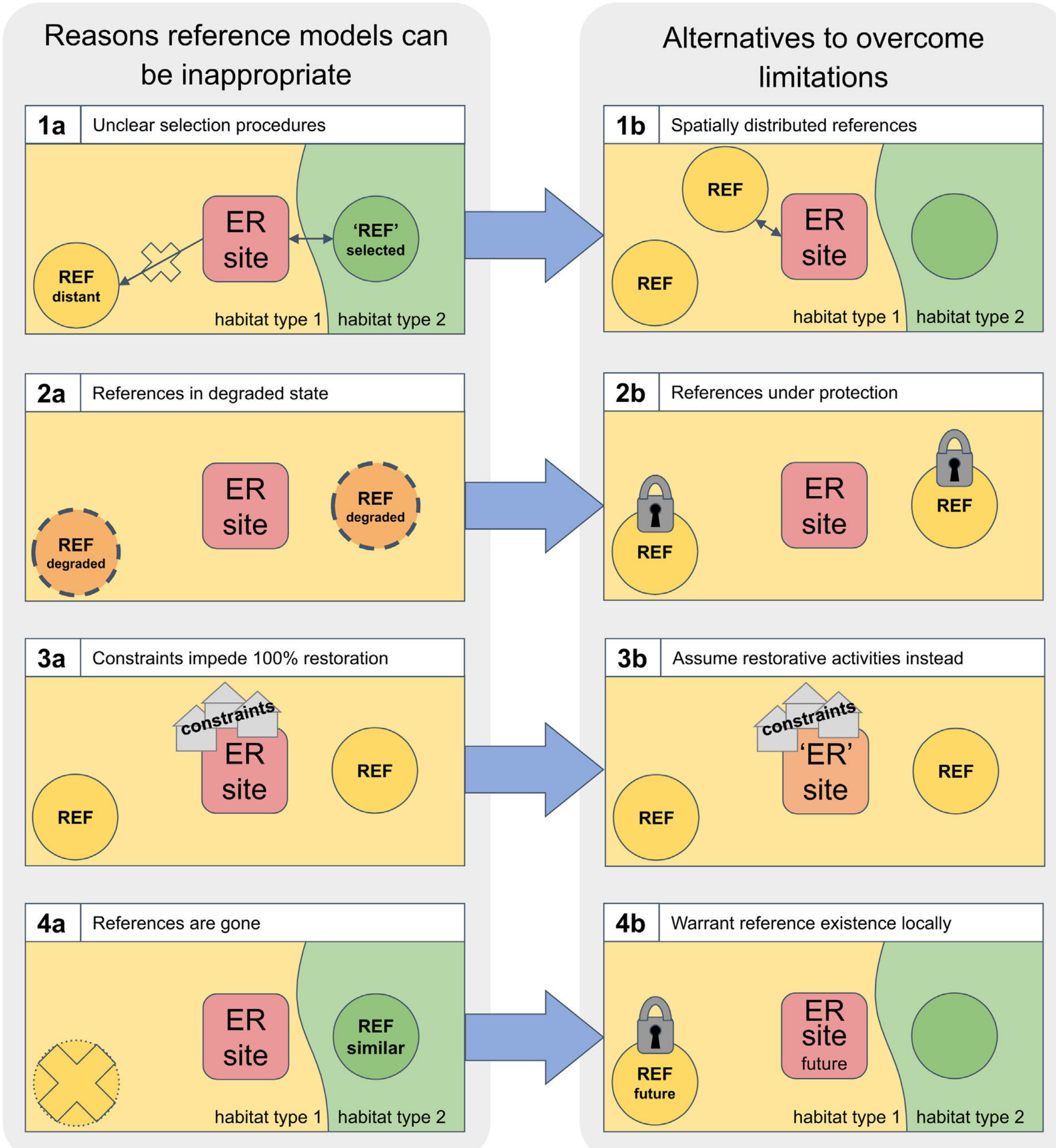


Fig. I. Suggested applications of optimal references to overcome common issues when selecting reference sites. Selection procedures are unclear due to the absence of appropriate references close to the restoration site (1a), which could be avoided with spatially distributed references (1b). References exist but are in a degraded state for not being protected (2a), should thus be under protection (2b). Constraints at the restoration site might impede restoration (3a), thus restorative activities should be implemented (3b). The absence of references, chiefly in highly altered landscapes (4a) should be avoided through especial assessment of the risk of losing references in landscapes under high land use change pressure (4b).

in consideration of a specific restoration site; otherwise, it is solely a remnant ecosystem. Importantly, both appropriate reference sites and optimal references are sites rather than models. The difference between sites and models appears to be subtle (Fig. 1), but sites are physical whilst models are normally sets of information. Therefore, assuming optimal references are sites can help bridge restoration and conservation: in order to have appropriate optimal references in the future, we need to protect them now. As we do not know today which sites will be needed in the future, we today need to guarantee the protection of the diversity of habitat types in a given landscape (see Box 2).

Integrating conservation and restoration to safeguard optimal references in key regions

Tropical regions still harbor a considerable amount of exceptionally or relatively intact terrestrial ecosystems (Williams et al., 2020), but many of them suffer rapid land use change and degradation (e.g., Overbeck et al., 2015; Fernandes et al., 2020). Additionally, restoration and conservation share at least two important limitations in the tropics. First, tropical regions harbor a large portion of the global biodiversity, which until today remains relatively unknown (e.g., Laurance and Edwards, 2011).

Box 2. Example: hypothetical representation of protection currently required by law and expected considering optimal references using the Brazilian Cerrado

The Cerrado, occupying ca. 2,2 million km^2 (equivalent to the area of Mexico), is located in Central Brazil. Vegetation is a mosaic of savannas, grasslands and forests, with 25 distinct vegetation types (Ribeiro and Walter, 2008). An estimated 50% of Cerrado area was converted, 20% remains undisturbed, and only 9% is legally protected (Pacheco et al., 2018).

Brazilian regulations limit use of natural ecosystems in private properties. In the Cerrado, 20% or 35% (when in the legal Amazon) of the property must remain as Legal Reserve (LR), i.e., cannot be converted to other land use (Fig. II-a), along with additional portions of the land to be protected around waterbodies, mountaintops, and springs (Fig. II-b). Yet, few requirements encompass specific biological features such as threatened ecosystems or habitats.

We represented a simplified arrangement of habitat types in a hypothetical property (Fig. II-c). In reality, many properties in the Cerrado are very large and thus likely harbor a range of habitats. Regulations are silent in designating which portions of a property should be defined as LR – there is even room for *ex situ* compensation that enables virtually 100% land conversion (Freitas et al., 2017). By taking optimal references into consideration (Fig. II-d), the decision where the LR should be placed should lead to substantial benefits for conservation.

In Fig. II-e, we present a hypothetical worst-case scenario of virtually no connectivity between non-converted areas. Yet, if habitats are regionally distributed as in Fig. II-f, certain habitat types would be completely converted. Taking optimal references into account, the spatial refining of value among areas is expected to reconfigure conservation options and probably add a further layer of legal requirements.

The choice on areas to keep as LRs is, in the current practice, usually biased towards forested ecosystems (Overbeck et al., 2015). Therefore, if we take habitat type 1 as a forested ecosystem, it would likely be focused on prioritization schemes, leaving other habitat types aside (and under no protection). Under a worst-case scenario, overlooked habitat types could eventually be regionally rare and the lack of optimal references can hinder restoration in the future. Considering optimal references is expected to leverage such limitations at the landscape scale with considerable contributions to conservation and restoration.

Therefore, we risk overlooking unknown biodiversity when restoring an area, as has also been reported for conservation (El-Gabbas et al., 2020). Second, research on ecological restoration in tropical countries is dismally insufficient to inform restoration planning and implementation needs, even though specific regions may be more advanced, as exemplified by the Brazilian Atlantic Forest and Costa Rica (Crouzeilles et al., 2019; Fagan et al., 2020). These limitations lead to an array of technical difficulties when implementing restoration in the tropics (detailed in the previous section, see also Box 1). Therefore, every potential tool and information should be used to properly restore tropical ecosystems, and strengthening the integration between restoration and conservation is a promising way (Possingham et al., 2015; Young, 2000).

Global conservation initiatives are currently under review for the establishment of post-2020 targets (Visconti et al., 2019). Overall, vast protected areas were delimited in the last decades throughout the globe, even though biodiversity gains have been questioned (Barnes et al., 2018; Wintle et al., 2019). Biodiversity risks having limited focus in conservation prioritization since the selection of protected areas has mainly given an overestimated value to reducing opportunity costs (Zwiener et al., 2017; Barnes et al., 2018; Baldi et al., 2019; Wintle et al., 2019). Consequently, reserve networks are usually composed of a restricted set of places away from populated areas and with low commercial value (Margules and Pressey, 2000; Barnes et al., 2018; Wintle et al., 2019). Heavily transformed regions where few patches remain (either protected or not) are not considered for conservation efforts (Baldi et al., 2019; Wintle et al., 2019; Zwiener et al., 2017).

Although reserve networks often overlook small remnants, protecting them can effectively contribute to the preservation of ecosystems/habitats (Kattan and Alvarez-López, 1996; Tulloch et al., 2016; Wintle et al., 2019), ultimately reducing the risk of entire ecosystems collapsing (Keith et al., 2015). Small remnants are subjected to clearing without much regulatory constraints in several countries (Tulloch et al., 2016; Box 2) although they often represent a significant portion of ecosystem remnants (Tulloch et al., 2016; Mangueira et al., 2021). This is probably the case in the Atlantic Forest where 12% of the original area is left, mainly in clusters of larger remnants far away from populated or arable areas or in small, scattered fragments (Zwiener et al., 2017). Although the conservation value of such remnants might be disputable due to fragmentation (Fahrig, 2019), they can be beneficial at the landscape scale (Kattan and Alvarez-López, 1996; Young, 2000; Tulloch et al., 2016; Wintle et al., 2019; Arroyo-Rodríguez et al., 2020; Mangueira et al., 2021). As for restoration, small remnants are expected to harbor important information through ecological memory that can function as references (Balaguer et al., 2014) and contribute to future restoration initiatives, especially for initiatives intended to restore areas of similar size in their vicinity (Fig. 2B). Therefore, small remnants often match the optimal references concept we propose here; evidently, large remnants match the optimal references concept as well, though they are more likely to be protected (e.g., Baldi et al., 2019).

Restoration prioritization studies have increased in number, including an assessment of global priority areas for restoration (Strassburg et al., 2020, but see Fleischman et al., 2022, for critique). However, such large-scale exercises do not capture – and, thus, fail in prioritizing – ecosystem representativeness: Strassburg et al., 2020 separated ecosystems into only five types. The incipient knowledge on ecosystem types especially in tropical regions is an important limitation in conservation and restoration planning (but see Keith et al., 2022). For instance, the understanding of ecosystem and habitat types was fundamental in the establishment of the Natura 2000 network in Europe (Campagnaro et al., 2019). In contrast, not having a clear idea on ecosystem representativeness can lead to the loss of unique ecosystems before they are even characterized, classified, or studied in more detail (e.g., Rupestrian grasslands in Brazil, Fernandes et al., 2016, 2020). For restoration prioritization, as exemplified for Colombia, Etter et al. (2020) showed that when the recently released IUCN Red list of Ecosystems is considered, there is only 12% overlap with the priority areas for restoration selected by the National plan. Without addressing ecosystem representativeness, we risk, in ecological restoration, homogenizing ecosystems in the highly diverse tropical region (Holl et al., 2022), with serious future consequences for biodiversity, species survival and ecosystem services provisioning.

Perspectives and implications

Optimal references are likely to contribute significantly to the restoration process in contrast to the use of suboptimal references or even not using any reference ecosystem. This is remarkably relevant in light of major limitations for tropical restoration and conservation addressed here, as conservation of small remnants in highly transformed landscapes becomes a priority to ensure the future of restoring those landscapes.

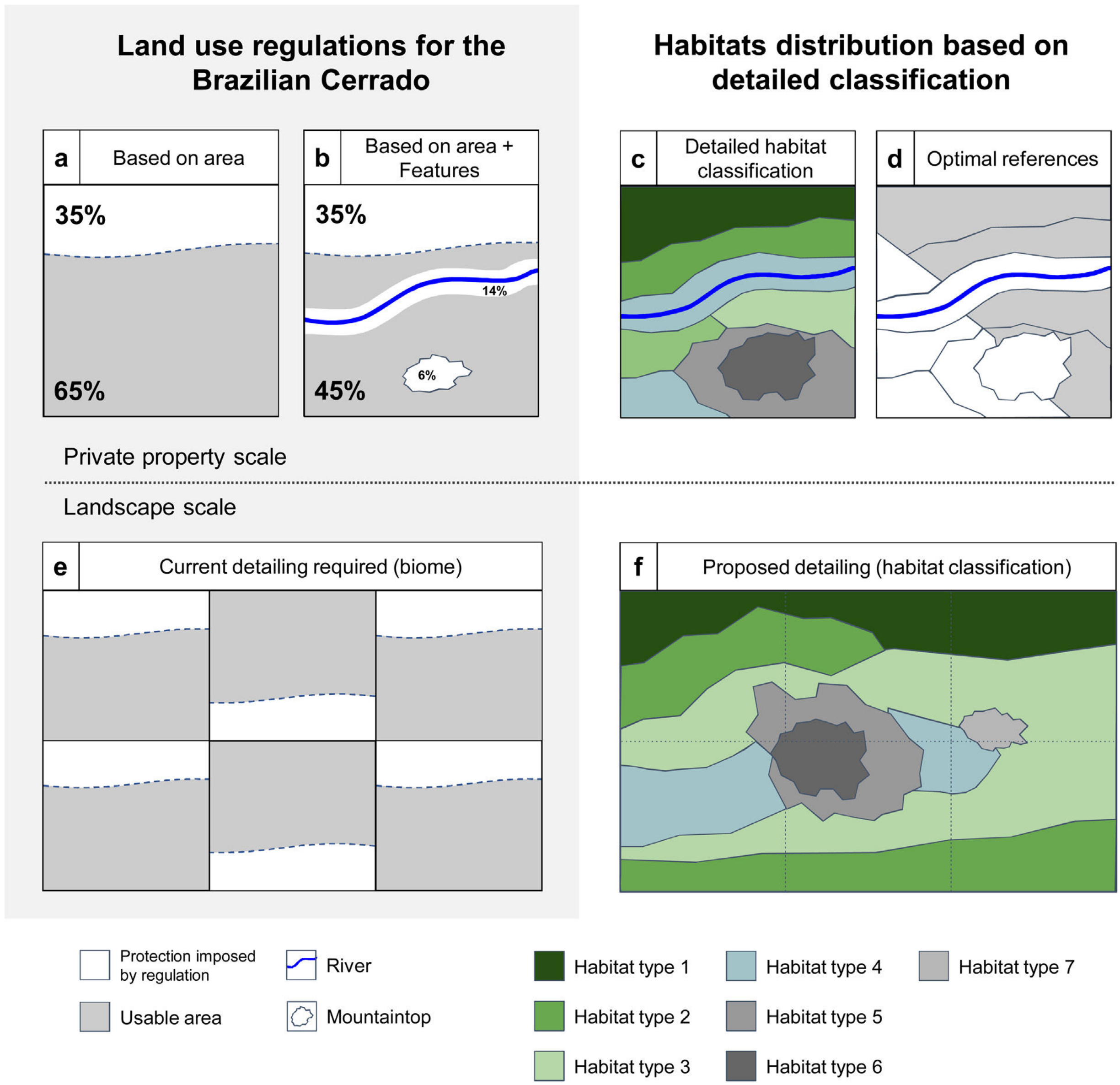


Fig. II. Comparison of current protection imposed by regulations and suggested protection based on habitat classification that would guide the application of optimal references in restoration - exemplified for the Brazilian Cerrado. Current protection is illustrated in a and b for the scale of a single private property: general norm for private properties within the Brazilian Cerrado (a); example of two features considered by norms, considering the property does not comply with legal terms that allow deducting area protected by the features (b). For the consideration of optimal references (c and d), a detailed habitat classification is needed, as illustrated in (c); taking habitat classification into consideration, areas protected based on optimal references could be set as in (d). At the landscape scale, hypothetical application of current norms regulating land use in six private properties (rectangles) are illustrated in (e), contrasted with habitat distribution obtained with a more detailed classification (f). For simplicity, in (e) and (f) we did not represent eventual features that would require additional protection.

In this context, strategic approaches are necessary, especially in highly degraded regions. Prioritizing the protection of reference areas can be integrated into the design and management of reserve networks. In order to supply the prioritization of optimal references protection, we highlighted the importance of creating detailed ecosystem classifications where they are lacking and developing approaches such as the IUCN Red List of Ecosystems (Keith et al., 2015, 2022; Etter et al., 2020). This would also allow selecting optimal references for conservation (and later guiding restoration), specifically for different habitat types.

In summary, defining and protecting optimal references is part of a strategic approach to tackle current and forthcoming challenges in conservation and restoration. Therefore, it deserves consideration from the scientific community, practitioners and decision makers.

Declaration of interests

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Declaration of Competing Interest

The authors report no declarations of interest.

Acknowledgements

We thank Kerrie Wilson for insights and comments on earlier versions of the manuscript. We also thank José M.D. Torezan, Pedro M.A. Ferreira, Sandra C. Müller, Carolina Murcia and one anonymous reviewer for comments on an earlier version of the manuscript. This study was supported by CAPES (TSPT, #6170/13-7), Fapemig (GWF), CNPq (GWF, GO, MMJ, TT), PPBio/MCTI and the Knowledge Centre on Biodiversity - Brazil/CNPq (GWF, GO, TT).

References

Arroyo-Rodríguez, V., Fahrig, L., Tabarelli, M., Watling, J.I., Tischendorf, L., Benchimol, M., Cazetta, E., Faria, D., Leal, I.R., Melo, F.P.L., Morante-Filho, J.C., Santos, B.A., Arasa-Gisbert, R., Arce-Peña, N., Cervantes-López, M.J., Cudney-Valenzuela, S., Galán-Acedo, C., San-José, M., Vieira, I.C.G., Slik, J.W.F., Nowakowski, A.J., Tscharntke, T., 2020. Designing optimal human-modified landscapes for forest biodiversity conservation. Ecol. Lett. 23, 1404–1420, http://dx.doi.org/10.1111/ele.13535.

Balaguer, L., Escudero, A., Martín-Duque, J.F., Mola, I., Aronson, J., 2014. The historical reference in restoration ecology: Re-defining a cornerstone concept. Biol. Conserv. 176, 12–20, http://dx.doi.org/10.1016/j.biocon.2014.05.007.

Baldi, G., Schauman, S., Texeira, M., Marinaro, S., Martin, O.A., Gandini, P., Jobbágy, E.G., 2019. Nature representation in South American protected areas: country contrasts and conservation priorities. PeerJ 7, e7155, http://dx.doi.org/10.7717/peerj.7155.

Barnes, M.D., Glew, L., Wyborn, C., Craigie, I.D., 2018. Prevent perverse outcomes from global protected area policy. Nat. Ecol. Evol. 2, 759–762, http://dx.doi.org/10.1038/s41559-018-0501-y.

Campagnaro, T., Sitzia, T., Bridgewater, P., Evans, D., Ellis, E.C., 2019. Half earth or whole earth: what can Natura 2000 teach us? Bioscience 69, 117–124, http://dx.doi.org/10.1093/biosci/biy153.

Clewell, A.F., Aronson, J.,2013. Ecological References. In: in: Ecological Restoration. Island Press/Center for Resource Economics, Washington, DC, pp. 137–153, http://dx.doi.org/10.5822/978-1-59726-323-8_7.

Cross, A.T., Nevill, P.G., Dixon, K.W., Aronson, J., 2019. Time for a paradigm shift toward a restorative culture. Restor. Ecol. 27, 924–928, http://dx.doi.org/10.1111/rec.12984.

Crouzeilles, R., Ferreira, M.S., Chazdon, R.L., Lindenmayer, D.B., Sansevero, J.B.B., Monteiro, L., Iribarrem, A., Latawiec, A.E., Strassburg, B.B.N., 2017. Ecological restoration success is higher for natural regeneration than for active restoration in tropical forests. Sci. Adv. 3, e1701345, http://dx.doi.org/10.1126/sciadv.1701345.

Crouzeilles, R., Santiami, E., Rosa, M., Pugliese, L., Brancalion, P.H.S., Rodrigues, R.R., Metzger, J.P., Calmon, M., Scaramuzza, C.A. de M., Matsumoto, M.H., Padovezi, A., Benini, R., de, M., Chaves, R.B., Metzker, T., Fernandes, R.B., Scarano, F.R., Schmitt, J., Lui, G., Christ, P., Vieira, R.M., Senta, M.M.D., Malaguti, G.A., Strassburg, B.B.N., Pinto, S., 2019. There is hope for achieving ambitious Atlantic Forest restoration commitments. Perspect. Ecol. Conserv. 17, 80–83, http://dx.doi.org/10.1016/j.pecon.2019.04.003.

El-Gabbas, A., Gilbert, F., Dormann, C.F., 2020. Spatial conservation prioritisation in data-poor countries: a quantitative sensitivity analysis using multiple taxa. BMC Ecol. 20, 35, http://dx.doi.org/10.1186/s12898-020-00305-7.

Etter, A., Andrade, A., Nelson, C.R., Cortés, J., Saavedra, K., 2020. Assessing restoration priorities for high-risk Ecosystems: An application of the IUCN Red List of Ecosystems. Land Use Policy 99, 104874, http://dx.doi.org/10.1016/j.landusepol.2020.104874.

Fagan, M.E., Reid, J.L., Holland, M.B., Drew, J.G., Zahawi, R.A., 2020. How feasible are global forest restoration commitments? Conserv. Lett. 13, 1–8, http://dx.doi.org/10.1111/conl.12700.

Fahrig, L., 2019. Habitat fragmentation: A long and tangled tale. Glob. Ecol. Biogeogr. 28, 33–41, http://dx.doi.org/10.1111/geb.12839.

Fernandes, G., Wilson Toma, T.S.P., Angrisano, P., Overbeck, G., 2016. Challenges in the Restoration of Quartzitic and Ironstone Rupestrian Grasslands. In: Fernandes, G.W. (Ed.), Ecology and Conservation of Mountaintop Grasslands in Brazil. Springer International Publishing, Switzerland, pp. 449–477, http://dx.doi.org/10.1007/978-3-319-29808-5_19.

Fernandes, G.W., Arantes-Garcia, L., Barbosa, M., Barbosa, N.P.U., Batista, E.K.L., Beiroz, W., Resende, F.M., Abrahão, A., Almada, E.D., Alves, E., Alves, N.J., Angrisano, P., Arista, M., Arroyo, J., Arruda, A.J., Bahia, T., de, O., Braga, L., Brito, L., Callisto, M., Caminha-Paiva, D., Carvalho, M., Conceição, A.A., Costa, L.N., Cruz, A., Cunha-Blum, J., Dagevos, J., Dias, B.F.S., Pinto, V.D., Dirzo, R., Domingos, D.Q., Echternacht, L., Fernandes, S., Figueira, J.E.C., Fiorini, C.F., Giulietti, A.M., Gomes, A., Gomes, V.M., Gontijo, B., Goulart, F., Guerra, T.J., Junqueira, P.A., Lima-Santos, D., Marques, J., Meira-Neto, J., Miola, D.T.B., Morellato, L.P.C., Negreiros, D., Neire, E., Neves, A.C., Neves, F.S., Novais, S., Oki, Y., Oliveira, E., Oliveira, R.S., Pivari, M.O., Junior, E.P., Ranieri, B.D., Ribas, R.P., Scariot, A., Schaefer, C.E., Sena, L., da Silva, P.G., Siqueira, P.R., Soares, N.C., Soares-Filho, B., Solar, R., Tabarelli, M., Vasconcellos, R., Vilela, E., Silveira, F.A.O., 2020. Biodiversity and ecosystem services in the Campo Rupestre: A road map for the sustainability of the hottest Brazilian biodiversity hotspot. Perspect. Ecol. Conserv. 18, 213–222, http://dx.doi.org/10.1016/j.pecon.2020.10.004.

Fleischman, F., Coleman, E., Fischer, H., Kashwan, P., Pfeifer, M., Ramprasad, V., Rodriguez Solorzano, C., Veldman, J.W., 2022. Restoration prioritization must be informed by marginalized people. Nature 607 (7918), E5–E6, http://dx.doi.org/10.1038/s41586-022-04733-x.

Freitas, F.L.Mde, Sparovek, G., Mörtberg, U., Silveira, S., Klug, I., Berndes, G., 2017. Offsetting legal deficits of native vegetation among Brazilian landholders: Effects on nature protection and socioeconomic development. Land Use Policy 68, 189–199, http://dx.doi.org/10.1016/j.landusepol.2017.07.014.

Gann, G.D., McDonald, T., Walder, B., Aronson, J., Nelson, C.R., Jonson, J., Hallett, J.G., Eisenberg, C., Guariguata, M.R., Liu, J., Hua, F., Echeverría, C., Gonzales, E., Shaw, N., Decleer, K., Dixon, K.W., 2019. International principles and standards for the practice of ecological restoration. Second edition. Restor. Ecol 27, S1–S46, http://dx.doi.org/10.1111/rec.13035.

Higgs, E.S., Falk, D.A., Guerrini, A., Hall, M., Harris, J., Hobbs, R.J., Jackson, S.T., Rhemtulla, J.M., Throop, W., 2014. The changing role of history in restoration ecology. Front. Ecol. Environ. 12, 499–506, http://dx.doi.org/10.1890/110267.

Hobbs, R.J., Arico, S., Aronson, J., Baron, J.S., Bridgewater, P., Cramer, V.A., Epstein, P.R., Ewel, J.J., Klink, C.A., Lugo, A.E., Norton, D., Ojima, D., Richardson, D.M., Sanderson, E.W., Valladares, F., Vila, M., Zamora, R., Zobel, M., 2006. Novel ecosystems: theoretical and management aspects of the new ecological world order. Glob. Ecol. Biogeogr. 15, 1–7, http://dx.doi.org/10.1111/j.1466-822X.2006.00212.x.

Hobbs, R.J., Higgs, E.S., Harris, J.A., 2009. Novel ecosystems: implications for conservation and restoration. Trends Ecol. Evol. 24, 599–605, http://dx.doi.org/10.1016/j.tree.2009.05.012.

Holl, K.D., Luong, J.C., Brancalion, P.H., 2022. Overcoming biotic homogenization in ecological restoration. Trends Ecol. Evol. 37, 777–788, http://dx.doi.org/10.1016/j.tree.2022.05.002.

Kattan, G.H., Alvarez-López, H., 1996. Preservation and management of biodiversity in fragmented landscapes in the Colombian Andes. In: Schelhas, J., Greenberg, R. (Eds.), Forest remnants in the tropical landscape. Island Press, Washington, pp. 3–18.

Keith, D.A., Rodríguez, J.P., Brooks, T.M., Burgman, M.A., Barrow, E.G., Bland, L., Comer, P.J., Franklin, J., Link, J., McCarthy, M.A., Miller, R.M., Murray, N.J., Nel, J., Nicholson, E., Oliveira-Miranda, M.A., Regan, T.J., Rodríguez-Clark, K.M., Rouget, M., Spalding, M.D., 2015. The IUCN Red List of Ecosystems: Motivations, Challenges, and Applications. Conserv. Lett. 8, 214–226, http://dx.doi.org/10.1111/conl.12167.

Keith, D.A., Ferrer-Paris, J.R., Nicholson, E., Bishop, M.J., Polidoro, B.A., Ramirez-Llodra, E., Tozer, M.G., Nel, J.L., Mac Nally, R., Gregr, E.J., Watermeyer, K.E., Essl, F., Faber-Langendoen, D., Franklin, J., Lehmann, C.E.R., Etter, A., Roux, D.J., Stark, J.S., Rowland, J.A., Brummitt, N.A., Fernandez-Arcaya, U.C., Suthers, I.M., Wiser, S.K., Donohue, I., Jackson, L.J., Pennington, R.T., Iliffe, T.M., Gerovasileiou, V., Giller, P., Robson, B.J., Pettorelli, N., Andrade, A., Lindgaard, A., Tahvanainen, T., Terauds, A., Chadwick, M.A., Murray, N.J., Moat, J., Pliscoff, P., Zager, I., Kingsford, R.T., 2022. A function-based typology for Earth's ecosystems. Nature 610 (7932), 513–518, http://dx.doi.org/10.1038/s41586-022-05318-4.

Laurance, W.F., Edwards, D.P., 2011. The search for unknown biodiversity. Proc. Natl. Acad. Sci. 108, 12971–12972, http://dx.doi.org/10.1073/pnas.1110319108.

Mangueira, J.R.S.A., Vieira, L.T.A., Azevedo, T.N., Sabino, A.P.S., Ferraz, K.M.P.M.B., Ferraz, S.F.B., Rother, D.C., Rodrigues, R.R., 2021. Plant diversity conservation in highly deforested landscapes of the Brazilian Atlantic Forest. Perspect. Ecol. Conserv. 19, 69–80, http://dx.doi.org/10.1016/j.pecon.2020.12.003.

Margules, C.R., Pressey, R.L., 2000. Systematic conservation planning. Nature 405, 243–253, http://dx.doi.org/10.1038/35012251.

Murcia, C., Aronson, J., Kattan, G.H., Moreno-Mateos, D., Dixon, K., Simberloff, D., 2014. A critique of the 'novel ecosystem' concept. Trends Ecol. Evol. 29, 548–553, http://dx.doi.org/10.1016/j.tree.2014.07.006.

Murcia, C., Guariguata, M.R., Andrade, Á., Andrade, G.I., Aronson, J., Escobar, E.M., Etter, A., Moreno, F.H., Ramírez, W., Montes, E., 2016. Challenges and prospects for scaling-up ecological restoration to meet international commitments: Colombia as a case study. Conserv. Lett. 9, 213–220, http://dx.doi.org/10.1111/conl.12199.

Overbeck, G.E., Vélez-Martin, E., Scarano, F.R., Lewinsohn, T.M., Fonseca, C.R., Meyer, S.T., Müller, S.C., Ceotto, P., Dadalt, L., Durigan, G., Ganade, G., Gossner, M.M., Guadagnin, D.L., Lorenzen, K., Jacobi, C.M., Weisser, W.W., Pillar, V.D., 2015. Conservation in Brazil needs to include non-forest ecosystems. Divers. Distrib. 21, 1455–1460, http://dx.doi.org/10.1111/ddi.12380.

Pacheco, A.A., Neves, A.C.O., Fernandes, G.W., 2018. Uneven conservation efforts compromise Brazil to meet the Target 11 of Convention on Biological Diversity. Perspect. Ecol. Conserv. 16, 43–48, http://dx.doi.org/10.1016/j.pecon.2017.12.001.

Possingham, H.P., Bode, M., Klein, C.J., 2015. Optimal conservation outcomes require both restoration and protection. PLoS Biol. 13, e1002052, http://dx.doi.org/10.1371/journal.pbio.1002052.

Ribeiro, J.F., Walter, B.M.T., 2008. As principais fitofisionomias do bioma Cerrado. In: Sano, S.M., Almeida, S.P., Ribeiro, JoséFelipe (Eds.), Cerrado: ecologia e Flora. Embrapa Informação Tecnológica, Brasília, pp. 151–212.

Strassburg, B.B.N., Iribarrem, A., Beyer, H.L., Cordeiro, C.L., Crouzeilles, R., Jakovac, C.C., Braga Junqueira, A., Lacerda, E., Latawiec, A.E., Balmford, A., Brooks, T.M., Butchart, S.H.M., Chazdon, R.L., Erb, K.-H., Brancalion, P.H.S., Buchanan, G., Cooper, D., Díaz, S., Donald, P.F., Kapos, V., Leclère, D., Miles, L., Obersteiner, M., Plutzar, C., de M. Scaramuzza, C.A., Scarano, F.R., Visconti, P., 2020. Global priority areas for ecosystem restoration. Nature 586, 724–729, http://dx.doi.org/10.1038/s41586-020-2784-9.

Tulloch, A.I.T., Barnes, M.D., Ringma, J., Fuller, R.A., Watson, J.E.M., 2016. Understanding the importance of small patches of habitat for conservation. J. Appl. Ecol. 53, 418–429, http://dx.doi.org/10.1111/1365-2664.12547.
Visconti, P., Butchart, S.H.M., Brooks, T.M., Langhammer, P.F., Marnewick, D., Vergara, S., Yanosky, A., Watson, J.E.M., 2019. Protected area targets post-2020. Science 364, 239–241, http://dx.doi.org/10.1126/science.aav6886.
Williams, B.A., Venter, O., Allan, J.R., Atkinson, S.C., Rehbein, J.A., Ward, M., Di Marco, M., Grantham, H.S., Ervin, J., Goetz, S.J., Hansen, A.J., Jantz, P., Pillay, R., Rodríguez-Buriticá, S., Supples, C., Virnig, A.L.S., Watson, J.E.M., 2020. Change in terrestrial human footprint drives continued loss of intact ecosystems. One Earth 3, 371–382, http://dx.doi.org/10.1016/j.oneear.2020.08.009.
Wintle, B.A., Kujala, H., Whitehead, A., Cameron, A., Veloz, S., Kukkala, A., Moilanen, A., Gordon, A., Lentini, P.E., Cadenhead, N.C.R., Bekessy, S.A., 2019. Global synthesis of conservation studies reveals the importance of small habitat patches for biodiversity. Proc. Natl. Acad. Sci. 116, 909–914, http://dx.doi.org/10.1073/pnas.1813051115.
Young, T.P., 2000. Restoration ecology and conservation biology. Biol. Conserv. 92, 73–83, http://dx.doi.org/10.1016/S0006-3207(99)00057-9.
Zwiener, V.P., Padial, A.A., Marques, M.C.M., Faleiro, F.V., Loyola, R., Peterson, A.T., 2017. Planning for conservation and restoration under climate and land use change in the Brazilian Atlantic Forest. Divers. Distrib. 23, 955–966, http://dx.doi.org/10.1111/ddi.12588.