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PECON-180; No. of Pages 12

ARTICLE IN PRESS

Perspectives in Ecology and Conservation xxx (xxxx) xxx–xxx

ABECO ASSOCIAÇÃO BRASILEIRA DE CIÊNCIA ECOLÓGICA E CONSERVAÇÃO

Perspectives in ecology and conservation

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Essays and Perspectives

Collaborative management as a way to enhance Araucaria Forest resilience

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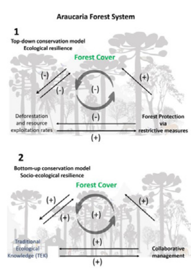
HIGHLIGHTS

- Top-down restrictive measures are the basis of Araucaria Forest System conservation
- Bottom-up collaborative management could favor keystone plant *Araucaria angustifolia*
- Top-down model had negative feedback that dampens the system limiting its resilience
- Bottom-up model had positive feedback expanding the system and its general resilience
- Collaborative management could maintain the Araucaria Forests System in the long term

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 7 September 2020
Accepted 1 March 2021
Available online xxx

Keywords:
Araucaria Forest System
Cultural keystone species
Ecological Keystone Species
Ethnoecology
Mixed Ombrophilous Forest
Participatory conservation
Resilience-thinking.

ABSTRACT

People and nature interact since millennia in forests worldwide, but current management strategies addressing these ecosystems often exclude local people from the decision-making process. This top-down approach is the cornerstone of conservation initiatives, particularly in highly threatened and fragmented forested ecosystems. In contrast, collaborative management involving the participation of local communities has increasingly contributed to conservation efforts globally. Here we ask how collaborative management would contribute to the conservation of a threatened, culturally important, and keystone tree species. We address this question in the Araucaria Forest System[1] (AFS) in southern Brazil, where the main conservation strategy has been top-down based on restrictive use. Throughout the entire distribution of AFS, we interviewed 97 smallholders about how they use and manage *Araucaria angustifolia* trees (araucaria). We integrated their Traditional Ecological Knowledge[2] (TEK) with a literature review about the conservation status of Araucaria Forests to analyze potential outcomes of two alternative conservation models: top-down with restrictive use, and bottom-up with collaborative management. We identified the feedback mechanisms in each model, and how they dampen or self-reinforced critical processes for AFS resilience. Our models showed that a top-down strategy maintains forest cover resilient to illegal logging but at the cost of losing TEK (undermining socio-ecological resilience) and forest resilience to

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[1] Araucaria Forest System – AFS
[2] Traditional Ecological Knowledge – TEK

https://doi.org/10.1016/j.pecon.2021.03.002

other external disturbances, such as climate change. Alternatively, a bottom-up approach based on successful collaborative management schemes may increase the general resilience of AFS, while preserving TEK, thus contributing to maintaining the entire social-ecological system. Our findings indicate how it is paramount to maintain TEK to conserve AFS in the long term through collaborative management. By including local actors in the governance of AFS, its resilience is reinforced, promoting forest expansion, maintenance of TEK, and participatory conservation.

INTRODUCTION

In the human-in-nature perspective, Social-Ecological Systems (hereafter SES) are the integration of human societies with ecosystems promoting reciprocal feedbacks, interdependence, and resilience (Folke et al., 2010). The resilience of SES depends on their ability to adapt and remain within a stability domain in the face of disturbances and external stressors, i.e. it does not move beyond thresholds to an alternative state of equilibrium. The adaptability of SES enhances its resilience because it allows the system to adjust itself in the face of adversities (Berkes et al., 2000). Forests worldwide are perfect examples of SES given the long-term interaction between forests, plants, and peoples. In the largest conserved block of tropical forest in the world – the Amazon forest, for instance, multiple human management practices over millennia increased edible plant diversity and abundance within forest patches, particularly near to archaeological sites, contributing to enhancing food security and production (Levis et al., 2018).

One of the most emblematic SES of the subtropical Atlantic Forest is the Araucaria Forest System (hereafter AFS), also known as Araucaria Mixed Forest (Fig. 1). First, because of its dominant species, the candelabra-aspect tree *Araucaria angustifolia* (Bertol.) Kuntze, popularly known as araucaria, has a keystone role in ecosystem functioning, especially due to its nut-like seed, known as *'pinhão'*, which structures the associate vertebrate assemblage spatio-temporally (Bogoni et al., 2020; Oliveira-Filho et al., 2015).

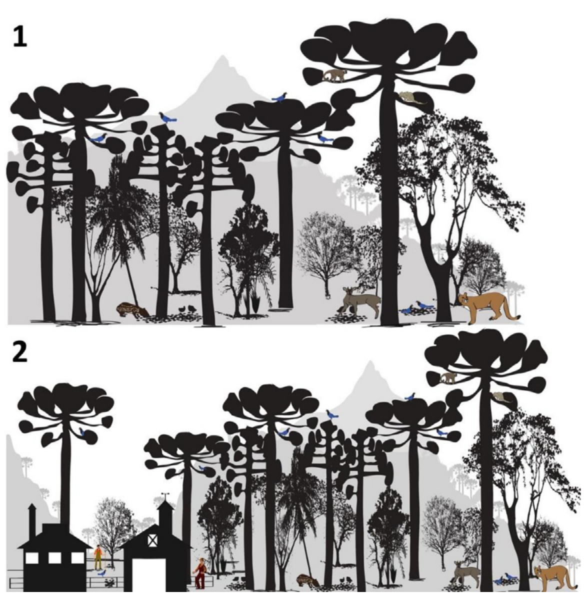


Fig. 1. Scheme of the Araucaria Forest System (adapted from Bogoni et al., 2020). **1. The Araucaria ecological system.** The araucaria (candelabra tree) and the typical ecological system under its canopy, such as *Ocotea sp.* – "Canela"; *Ilex paraguariensis* – "erva-mate"; *Dicksonia sellowiana* – "xaxim"; and *Acca sellowiana* – "goiabeira-serrana"; and representative fauna, such as the *Mazama gouazoubira* – "veado campeiro"; *Puma concolor* – "cougar"; *Dasyprocta azarae* – "cutia"; and *Cyanocorax caeruleus* – "azure Jay bird". **2. The Araucaria socio-ecological system.** We represented the current scenario of araucaria remnants, especially in southern Brazil, where local groups (smallholders; indigenous peoples) continue to manage the system since pre-Columbian times.

Second, because of its ancient connection with Indigenous peoples and local communities (IPLCs; Reis et al., 2014; Robinson et al., 2018). The araucaria was and still is widely used by local and indigenous groups due to the consumption of *pinhão* (Robinson et al., 2018), with high caloric content that helps coping with the winter seasons (Mello and Peroni, 2015). Araucaria seeds are part of intense traditional use, management, and commerce by smallholders as well as *pinhão* extractors across different regions of Southern and Southeastern Brazil (Adan et al., 2016; Mello and Peroni, 2015; Reis et al., 2014; Quinteiro et al., 2019; Tagliari and Peroni, 2018; Zechini et al., 2018). The comprehension that certain species are crucial to maintaining different cultures, such as smallholders or indigenous groups, was the basis to create the term "Cultural Keystone Species" (Garibaldi and Turner, 2004). Here we use a similar term "culturally important species", following Freitas et al. (2020), which considers the species overriding role in people's culture, although not necessarily indispensable for the survival of a specific culture. However, if a culturally important species is extinct locally or has suffered a population decline, it will strictly influence local peoples' subsistence and spirituality (Freitas et al., 2020), as well as the transmission of Traditional Ecological Knowledge (Berkes, 2009). Yet, given the intense commercial exploitation of *A. angustifolia* during the 20th century due to its high-quality wood (Wendling and Zanette, 2017), the species is currently classified as "*Critically Endangered"* according to the International Union for Conservation of Nature (IUCN, Thomas, 2013). Since then, the Brazilian legislation forbids any forms of araucaria logging and stimulates the creation and maintenance of top-down protective strategies. As a result, Strictly Protected areas are the cornerstone of conservation strategies related to Araucaria Forest Systems, which often exclude local and indigenous peoples from participating in biodiversity conservation (Zechini et al., 2018).

Protected Areas (PA) are well-known refuges for biodiversity and ecosystems, particularly in the Atlantic Forest, where most of the system persists in fragments surrounded by densely inhabited urban and rural areas (Scarano and Ceotto, 2015; Pacheco et al., 2018; Metzger et al., 2019). Although Protected Areas encompass only 4% to 6% of the current Araucaria Forest extent (Castro et al., 2019; Ribeiro et al., 2009), studies evaluating their effectiveness for araucaria conservation (Castro et al., 2019) did not take into account another major category: Legal Reserves – a special private PA. These compulsory private PAs host almost one-third of all remaining native vegetation in the Atlantic Forest (Metzger et al., 2019). Most of the native Araucaria Forest fragments occur within small farms (Bittencourt and Sebbenn, 2009). Consequently, it is undeniable that local smallholders also contribute to preserving, willingly or unwillingly, the Araucaria Forests. However, previous ethnoecological surveys have suggested that top-down strategies (i.e. maintenance and creation of Strictly Public Protected Areas and Private Protected Areas) may negatively impact the interactions between smallholders and araucaria trees (Adan et al., 2016; Tagliari and Peroni, 2018). For instance, because removing araucaria trees is illegal, some landowners do not depend on araucaria's resources, and thus are prone to actively prevent araucaria's natural regeneration by removing its seedlings from their properties before they reach maturity (Adan et al., 2016; Mello and Peroni, 2015; Quinteiro et al., 2019; Tagliari and Peroni, 2018). In this case, livestock farming (e.g. cattle), pasture or crop production for subsistence, such as corn or manioc, usually compete with araucaria's natural regeneration, creating a human-plant barrier (Adan et al., 2016; Tagliari and Peroni, 2018), where some landowners state that they lose the rights to use their lands because of protected species (Quinteiro et al., 2019).

The araucaria case is therefore a conservation dilemma: people and natural resources interact since millennia, but current management strategies often exclude local people from the decision-making process. Top-down strategies prevent local engagement in Araucaria Forest conservation. Furthermore, the contribution of top-down conservation strategies to the long-term conservation of nature, individually or globally, still lacks effectiveness (Rodrigues and Cazalis, 2020), especially regarding potential limitations to the protected area *per se*, such as socio-ecological resilience or climate change impacts (Ferro et al., 2014). In contrast, bottom-up strategies, developed together with local human groups through sharing decisions between governments, institutions and local resource users are more likely to produce benefits for the social-ecological system as a whole, besides strengthening ecosystem resilience (Folke et al., 2010; Bennett et al., 2016).

From the human-influenced expansion of Araucaria Forests during the past two millennia (Robinson et al., 2018) to the current highly productive systems – such as the "*faxinais*" – underneath araucaria canopies, combined with *Ilex paraguariensis*, locally known as "*yerba-mate*", a traditional tea-like beverage (Reis et al., 2018), humans are part of the Araucaria Forest System (Reis et al., 2014). The maintenance of traditional practices constitutes a generational body of knowledge, beliefs, and practices, known as Traditional Ecological Knowledge (TEK; sensu Berkes, 2009), which is fundamental for the persistence of social-ecological systems (Folke et al., 2005). In practice, local societies that manage ecosystems based on TEK contribute to maintaining culturally important species as well as human cultures resilient by a positive feedback mechanism (Cámara-Leret et al., 2019), and by doing so, this process also maintains the ecosystem resilient, particularly if management addresses a keystone species such as araucaria (Bogoni et al., 2020). Consequently, a crucial step to maintaining the Araucaria Forest System resilient is by managing the feedbacks within its system (Biggs et al., 2012; Musavengane, 2019; and see Fig. 1 comparing the Araucaria ecological and socio-ecological system).

Feedbacks are interactions in which the resulting effect either reinforces (positive) or dampens (negative) change (DeAngelis et al., 1986), influencing ecosystem dynamics. For instance, when trees establish in a fire-prone savanna landscape, they reduce fire spread, favoring forest expansion (van Nes et al. 2018). Particularly, the positive feedbacks, which self-reinforce changes, are capable of triggering cascading effects that push entire ecosystems to alternative states (Estes et al., 2011; Scheffer et al., 2001). Feedbacks depict the ecological processes that promote or degrade ecosystem resilience and functioning; and hence are the key mechanisms to be incorporated in ecosystem management (Briske et al., 2006). Both positive and negative feedbacks play major roles in the self-organization of social-ecological systems. Therefore, to manage resilience it is necessary to understand the most important feedbacks in the system, especially in vulnerable and threatened ecosystems, such as Araucaria Forests (Briske et al., 2006) where local peoples with deep ecological knowledge are likely to be critical partners.

Collaborative management (co-management) implies a participatory decision-making process in which the management of a natural resource is shared between users and other actors, such as national, and subnational governments, Non-Governmental Organizations (NGOs), and/or local cooperatives (Berkes and Davidson-Hunt, 2006). Garibaldi and Turner (2004) argue that if local people identify themselves with a certain species, they will have a strong desire to preserve or restore it. Preserving a culturally important species, therefore, may guarantee the participation of different actors in species' conservation programs, and consequently benefit both the species, local people, and its surrounding ecosystem (Cristancho and Vining, 2004; Garibaldi and Turner, 2004; Noble et al., 2016). Although studies addressing co-management schemes of culturally important species remain scarce in the literature due to the lack of ecological, social, and economic quantitative data, this bottom-up approach seems promising to effectively engage local people into conservation actions (Freitas et al., 2020). Furthermore, co-management may be part of resilience-thinking because it incorporates some of its main principles, according to Stockholm Resilience Centre (Stockholm Resilience Centre, 2013), such as the management of feedbacks and the participation of locals in the governance of the social-ecological system.

Applying resilience-thinking to local or regional conservation issues is still a great challenge because decision-makers are usually attached to traditional conservation strategies. In the case of Araucaria Forest Systems, where the main conservation strategy is focused on a top-down conservation model with restrictive use, uncertainties still exist whether a collaborative management scheme could contribute to improving conservation outcomes. Here we address this dilemma in a broad scale study to obtain detailed information on the state of the Araucaria Forest System and understand how both top-down and bottom-up conservation strategies may affect the resilience of this system, including its cultural and ecological dimensions. First, based on a comprehensive literature review, we analyze feedbacks and the resulting dynamics of two alternative conservation models: (1) top-down under restrictive use and (2) bottom-up with co-management schemes. Second, based on evidence from 97 semi-structured interviews with smallholders across the Araucaria Forest, we explored the risks and benefits of implementing both models. By presenting the key interactions and feedbacks that could strengthen local engagement for araucaria conservation, we expect to provide a critical perspective for managing and enhancing Araucaria Forest System resilience.

METHODS

Study area

The study was conducted in southern Brazil, across the entire extent of the Araucaria Forest ecoregion (Fig. 2) and covering four environments: Alluvial - on old terraces associated with the river system; Sub-montane - constituting disjunctions at altitudes below 400 m; Montane - located approximately between 400 and 1000 m of altitude; and High Montane - comprising altitudes above 1000 m (IBGE, 2012). The highland climate, where the escarpment rises ~1000 m from the Atlantic Forest coastal plain, is humid mesothermic; temperature range between 15-20 °C; and mean annual rainfall of 1500-2000 mm (Robinson et al., 2018). At its northeastern limit, the ecoregion experiences a tropical climate, and persists only at specific cold temperatures spots at higher altitudes, such as Mantiqueira hills, at the High Rio Preto Microbasin (Castro et al., 2019; Quinteiro et al., 2019).

Araucaria policies and legislation

Several categories of protected areas exist in Brazil: Conservation Units, which are divided into Strictly Protected Areas and Sustainable Use Areas, and are managed by federal, state, or municipal administration, or through partnerships with the private sector (De Moura et al., 2009); Permanent Preservation Areas and Legal

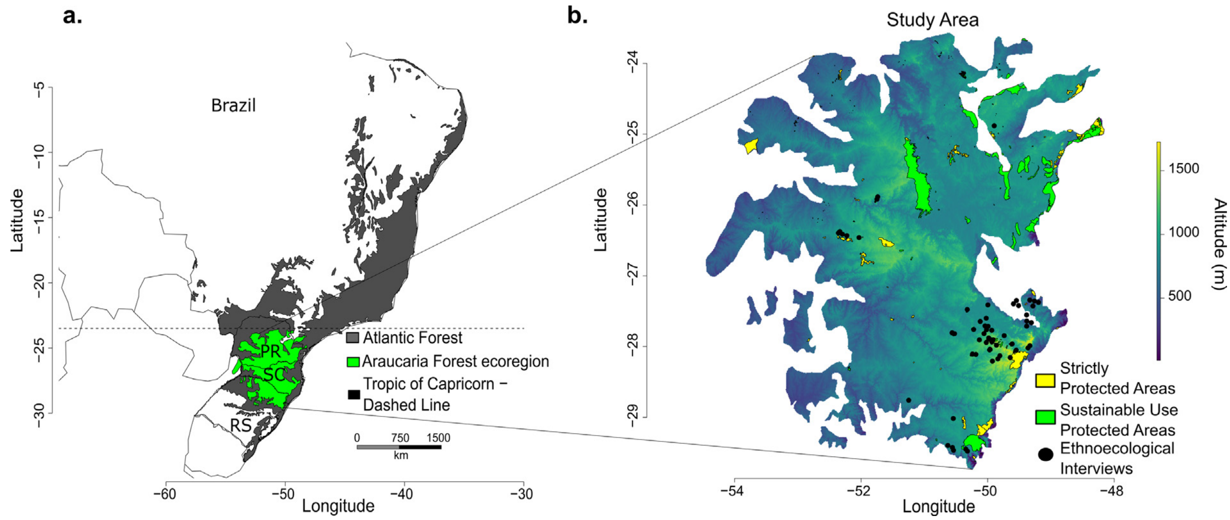


Fig. 2. **(a)** The Atlantic Forest (dark gray) with the Araucaria Forest ecoregion (green) showing the three Brazilian states which mainly encompass the ecoregion: Paraná (PR), Santa Catarina (SC), and Rio Grande do Sul (RS); **(b)** The Araucaria Forest altitude map and the distribution of Conservation Units: Strictly (yellow) and Sustainable Use Protected Areas (green); black dots represent the occurrence of 97 ethnoecological interviews in this study. We highlight that three interviews occurred at São Paulo state (beyond the Araucaria Forest ecoregion) at Cunha municipality.

Reserves (private protected areas within private properties); and Indigenous Lands (Pacheco et al., 2018). According to the Brazilian National System of Conservation Units (BRASIL, 2000), the Sustainable Use category is divided into seven sub-categories, of which two could be specially targeted to TEK holders in the Araucaria Forest System: Sustainable Development Reserves and Extractive Reserves. Both types of protected areas aim to safeguard the livelihoods and cultures of traditional social groups, as well as to conserve nature and its biodiversity (De Moura et al., 2009). Also, Extractive Reserves require some level of community organization and cooperation.

However, only 10.6 % of the Atlantic Forest (thus including the AFS) is encompassed by Conservation Units, mostly of Sustainable Use (75 %). Furthermore, from the 75 % of Sustainable Use Conservation Units created within the Atlantic Forest, only 0.45 % and 0.62 % are classified as Sustainable Development Reserves and Extractive Reserves, respectively (Pacheco et al., 2018). As a result, few protected areas in the AFS recognize the importance of traditional peoples. Also, Sustainable Use Conservation Units are managed by the state governments, contrary to Strictly Protected Areas – managed by Federal government –; and Indigenous Lands, which cover only 0.72 % of the AFS area (Pacheco et al., 2018), are administered by the Federal Indian Agency – FUNAI. Finally, almost one-third of Atlantic Forest's remaining native vegetation occurs within Legal Reserves and Permanent Preservation Areas, in private properties (Metzger et al., 2019). Consequently, most of the native Araucaria Forest occurs within small farms (Bittencourt and Sebbenn, 2009) and it is inspected by municipal, state, and federal agencies. Farmers who use and manage araucaria's resources are usually low-income smallholders who do not receive any financial return for conserving forested areas (Orellana and Vanclay, 2018). The lack of political incentives for Araucaria Forest's active management has led to illegal land-use practices within Legal Reserves (Orellana and Vanclay, 2018).

The Brazilian legislation prohibits any type of management of araucaria timber (Lei da Mata Atlântica or Atlantic Forest Law n° 11.428/2006; CONAMA Resolution n° 278/2001). However, the Paraná State recently approved a new Law n° 20.223/2020 (Paraná Official Diary, 2020), which regulates the planting and exploitation of *Araucaria angustifolia*, aiming to stimulate timber management programs. This new law defines and authorizes timber exploitation in private properties beyond restricted areas (e.g. Legal Reserves) and areas where illegal deforestation previously occurred within the Atlantic Forest. Yet, by promoting only timber exploitation, a new market is created for araucaria, possibly stimulating local populations under TEK systems to abandon their ancient practices. This alternative economic activity benefits landowners but may undermine the resilience of the social-ecological system in the long-term. We highlight that legislation should also promote, in this sense, the maintenance of Araucaria Forest stands ("*Floresta em Pé*") beyond Legal Reserves as potential areas for co-management initiatives via Payment for Environmental Services (Tagliari et al., 2019). Sustainable *pinhão* production and Araucaria Forest reforestation are some of the existing projects under the possibilities of Payment for Environmental Services (see Tagliari et al., 2019).

The Traditional Ecological Knowledge holders in the context of the study

Within the AFS different actors use, manage, and explore araucaria resources as opposing to other social groups who do not use them. Despite human management since Pre-Columbian times, where ethnic groups cultivated *pinhão* for subsistence and religiousness (Reis et al., 2014), during the 20th century, a combination of agriculture expansion, urbanization, and logging changed abruptly the AFS (Rezende et al., 2018; Ribeiro et al., 2009). Logging was especially relevant to decimate 97% of araucaria remnant populations since the beginning of the 20th century (Enright and Hill, 1995). This exploratory scenario culminated in several restrictive measures, such as logging prohibition, to protect the 'Critically Endangered' species for the IUCN Red List (Thomas et al., 2013).

In AFS, many social groups use and manage araucaria resources, but other social groups do not use or manage them. The latter relies mainly on livestock, agriculture, and farming systems for commerce and subsistence, while smallholders who use Araucaria Forest Systems depend economically on *pinhão* extraction and other associated crops (e.g., tobacco and yerba-mate) for their livelihoods (Adan et al., 2016; Quinteiro et al., 2019; Tagliari and Peroni, 2018). This interaction between traditional smallholders and AFS usually surpasses more than one generation, because they were born and raised in the same family's properties (Adan et al., 2016), where they might learn the processes of community organization and cooperation (Reis et al., 2018). We thus defined the specific group of smallholders and *pinhão* extractors distributed across Southern and Southeastern Brazil as Traditional Ecological Knowledge holders in the context of the study. This attribute indicates knowledge, use, and dependency on araucaria management. We proceeded with the application of the semi-structured questionnaire with TEK holders. Potential participants were indicated by informal conversations with smallholders and *pinhão* extractors in each municipality and with environmental specialists (such as municipalities or State environments bureaus, professors, and universities). We applied the snowball technique (Bernard, 2006) to follow the semi-structured interviews, where participants at the end of the interview recommended people directly involved in araucaria management. We recognize that indigenous peoples, such as Southern-Jê and Guarani, have shaped remnant forest composition in Southern Brazil (Cruz et al., 2020), and are also important TEK holders. However, due to ethical aspects and legal authorization we did not include indigenous peoples in our study.

Data collection from ethnoecological interviews and the literature

We conducted two strategies for data collection from the study area: fieldwork and a comprehensive literature review. To quantitatively assess the aspects of araucaria co-management with local smallholders and araucaria nut-like seeds extractors, we first identified key-regions in Southern and Southeastern Brazil where *pinhão* use, commerce, and management are commonly described (e.g. regional *pinhão* parties, such as "*Festa do Pinhão*" at Lages and Cunha municipalities; informal *pinhão* commerce along estate highways; and published literature). We thus conducted 97 semi-structured interviews with key-informants in four Brazilian States: Paraná, Santa Catarina, Rio Grande do Sul, and São Paulo (surroundings of Mantiqueira hills at Cunha municipality), covering 14 municipalities between March 2018 and January 2019 (Fig. 2). Prior to the application of the questionnaire to the participants, we obtained interviewees' consent following the code of ethics of the International Society of Ethnobiology. Our study was approved by the ethics committee of the Federal University of Santa Catarina (CAEE: 86394518.0.0000.0121). The semi-structured interview protocol addressed three main topics: (i) historical management and socioeconomic factors; (ii) the araucaria ecology and ethnoecology aspects; (iii) interviewees' perspectives about climate change threats for araucaria (see Table 1 and Table S1). To assess the local knowledge and state-of-the-art of araucaria co-management for this study, we selected specific open-ended questions through the questionnaire such as (i) "What is the importance of *pinhão* to your property?"; (ii) "What are the causes behind the expansion/retraction in araucaria's population?"; (iii) "How much *pinhão* (kg) has been gathered in your property on average?"; (iv) "How many ethnovarieties of araucaria can you identify in the landscape?"; (v) What are the differences in size, color, taste, ripening period of the ethnovarieties? (vi) "Do you practice any management during *pinhão* gathering?". Finally, we compiled this data to produce a theoretical framework that could support potential collaborative management arrangements. Pilot interviews preceded data collection to refine the semi-structured questionnaire in January and February 2018.

The comprehensive literature review was performed by using "*Web of Science*" search engine, following Bogoni et al. (2020) and Montaño-Centellas et al. (2020). We searched for specific terms in the abstracts of articles published between 2010 and -2020: "araucaria*" and "angustifolia*" and "conservation*" or "cultural*". Both terms "conservation" and "cultural" were defined because they are commonly employed in scientific publications targeting araucaria conservation and ethnoecological studies. We found 70 scientific peer-reviewed articles (Table S2) and included a few non-indexed references, such as Ph.D. theses. First, we cross-checked the literature review information with our fieldwork data. Second, we used the selected peer-reviewed articles to propose a schematic framework (Table S3) based on two alternative conservation models.

Top-down versus bottom-up conservation schemes for the Araucaria Forest System

To create the alternative conservation models, we followed the framework of complex adaptive systems, which understands that social-ecological systems are driven by external factors, such as policies and climate change, as well as by internal feedbacks (Berkes et al., 2000; Folke et al., 2010). We first identified '*Forest Cover*' as the main state variable defining the ecosystem from the conservation and a more holistic perspective. State variables are meant to represent the overall state of a system and may indicate the existence of alternative stable states (Folke et al. 2010). We then defined two variables representing drivers under a top-down conceptual framework: '*Deforestation and resource overexploitation*' and '*Forest Protection*'. For the bottom-up conceptual framework, we used a second state variable '*Traditional Ecological Knowledge - TEK*', and '*Collaborative management*' as a driver. These variables were previously identified as the most important for AFS dynamics in our literature review and represent critical elements in each conservation model (Table S3). For instance, one of the main goals of protected areas is halting biodiversity loss, such as deforestation (Rodrigues and Cazalis, 2020). In Brazil, both federal and state governments are responsible for top-down conservation models, especially in the form of Protected Areas, such as Strictly Protected and Sustainable Use Conservation Units, or Legal Reserves (Metzger et al., 2019; Pacheco et al., 2018). In contrast, we defined 'TEK' as another state variable under a bottom-up conservation model because araucaria can be classified as a Culturally Important Species that depend on 'TEK' to persist (Adan et al., 2016; Quinteiro et al., 2019; Reis et al., 2014; Tagliari and Peroni, 2018). Both conceptual models suggest that alternative feedback loops produce alternative dynamics of Araucaria Forest Systems. Following these two models, we propose the main threats, strategies, and actors involved, as well as the benefits and risks of bottom-up and top-down conservation strategies (inspired by Freitas et al., 2020). Finally, also based on the published literature and field data from this study that indicates the bottom-up scheme as the most promising for maintaining AFS in the future, we evaluate the possibilities for implementing collaborative managements that contribute to strengthening environmental governance in the region.

RESULTS

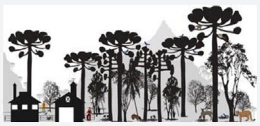
Socio-economic benefits and co-management possibilities for araucaria resources

According to our interviews, local smallholders and *pinhão* extractors are involved in the extraction of araucaria seeds (*pinhão)*, for at least 3.5 generations (mean = 3.8 generations, where each generation represents 25 years on average). There are family groups who have been living in the same region for 130-150 years (35 family groups or 36 %). This long interaction between the participants with araucaria's resources brings large socio-economic benefits to local families. Among the 97 participants, 63 (65%) told that somehow *pinhão* tradeinfluences their monthly incomes, from R$ 1000 to R$ 2500 per month, i.e. US$ 490 to US$ 1235 at the time, in 2018 (WBI, 2020) or ~1 to 2.3 Brazilian minimum wages in 2018. Furthermore, 17 participants among those 63 who benefited from trade affirmed that at least 50% of their annual gross income comes from *pinhão* trade. *Pinhão* trade is among the three main sources of income for 30% of all participants. Livestock and other crops were commonly cited by smallholders as alternative income sources, together with *pinhão* trade, such as beans, corn, yerba mate, and tobacco. The amount of *pinhão* gathered per season by the partici-

Table 1

Collaborative management of *Araucaria angustifolia* and its main challenges for implementation, considering: (i) Implications; (ii) potential benefits: cultural, ecological, social-economic, and institutional arrangements, as well as potential risks; and (iii) the literature review and interviews' data to sustain our model assumptions (inspired by Freitas et al., 2020). Co-management for araucaria considers mostly the use, management, and consumption of its nut-like seed, although other management systems exist, such as legal timber production, reforestation, maintenance of private native remnants, and payment for environmental services. We used information available in the literature to characterize the araucaria co-management framework. Here, we describe in detail the risks and benefits of the araucaria co-management.

Araucaria angustifolia co-management



Implications	Potential benefits	Reference
Cultural		
Participants' engagement (local people)	Increase	This study (questions A3; A3a; A7a; B2; B4; see Table S1)
Community involvement	Increase	This study (questions A3a; A7a; see Table S1); Adan et al., 2016
Societal recognition and outreach	Increase	Freitas et al., 2020
Strengthening of cultural values and Traditional Ecological Knowledge	Increase	Reis et al., 2014; Mello and Peroni, 2015; Adan et al., 2016; Tagliari and Peroni 2018
Maintenance of araucaria ethnovarieties	Increase	This study (questions B4; B5; B6; B13; B14b; B14c; B15; see Table S1); Adan et al., 2016; Tagliari and Peroni 2018; Quinteiro et al., 2019
Ecological		
Species abundance	Increase	This study (questions A7; A7a; B1; B13; B13b; see Table S1); Sühs et al., 2018
Araucaria Forest ecosystem conservation and recovery	Increase general resilience to human and natural disturbances	Folke et al., 2010
Ecological interactions	Increase	Bogoni et al., 2020
Nut-like seed production	Increase	This study (questions A3; A3a; B2; see Table S1); Robinson et al., 2018
Connectivity between araucaria's remnant populations	Maintenance of araucaria remnants through different Protected Areas	Tagliari et al., in review
Species' genetic diversity	Increase	Adan et al., 2016
Contribution to food security	Increase	This study (questions A3a; B2. B3; see Table S1); Reis et al., 2018
Social-economic		
Societal recognition and outreach	Increase	Reis et al., 2014
Stakeholders' participation	Possible	Tagliari et al., 2019
Possibility of financial self-sustainability	Possible	Tagliari et al., 2019
Income distribution within the community	Increase	This study (questions A3; A3a; A7a; see Table S1)
'Conservation-by-use' possibility	Possible	Reis et al., 2018
Historical commercial overpressure	Possible	Ribeiro et al., 2009; Mello and Peroni, 2015; Schneider et al., 2018
Value for sustainable araucaria resources use	Possible	Tagliari et al., 2019
Opportunities for institutional arrangements		
Surveillance/enforcement	Possibly increase	Freitas et al., 2020
Payment for Environmental Services as a compensation strategy	Possible	Tagliari et al., 2019
Main stimuli to local engagement	Cultural/moral/ethic aspects; financial compensation	This study (questions A3a; A7a; see Table S1); Tagliari et al., 2019
Rules focusing on habitat protection	Increase[2]	See footnote
Legal permission to trade the target species	There is no legal permission[3]	See footnote
Co-management with the consent of environmental agencies (such as timber production quotas for smallholders use and management)	Possible	Orellana and Vanclay, 2018
Financial compensation for supporting araucaria's remnants besides Legal Reserves and Permanent Preservation Areas	Increase	Tagliari et al., 2019
Potential risks		
Reduced inspection of environmental agencies	Possible	Freitas et al., 2020
Historical commercial overpressure	High	Ribeiro et al., 2009; Mello and Peroni, 2015; Schneider et al., 2018
Current illegal harvest pressure (i.e. deforestation and logging)	High	Adan et al., 2016; Schneider et al., 2018; Tagliari and Peroni 2018; Quinteiro et al., 2019

[1] Southern Brazilian States created their specific laws for the beginnings of *pinhão* commerce (i.e. Rio Grande do Sul starts from April 15th; Santa Catarina and Paraná from April 1st). This decision period is due to the maintenance of local fauna, especially the parrots "*Papagaio-charão*" and "*Papagaio-do-peito-roxo*" (*Amazona petrei* and *Amazona vinacea*, respectively), besides small rodents as "*cutia*" (*Dasyprocta azarae*), and mammals as "*veado*" (*Mazama gouazoubira*; Lob and Vieira, 2008). Once the extraction season begins no laws regulate the amount of *pinhão* (kg or tonne) collected during the season period.

[2] Mata Atlântica Law n° 11.428/2006 – prohibits native species management in natural forests. CONAMA Resolution N° 278/2001 (BRASIL, 2006; CONAMA - Conselho Nacional do Meio Ambiente, 2001).

[3] According to Brazilian legislation, araucaria native populations are prohibited for timber harvesting once the species is '*Critically Endangered*' (Thomas, 2013). However, planted araucaria harvesting following a management plan registered and approved by environmental agencies is allowed, but bureaucracy and lack of flexibility prevent this management plan (Wendling and Zanette, 2017).

pants was classified in three categories: (i) up to 1000 kg (40% or 39 participants); (ii) from 1000 to 10,000 kg (47.5% or 46 participants); and (iii) above 10,000 kg (11.5% or 11 participants). For most participants, however, the extractivism of araucaria seeds did not stand in practice as part of a co-management scheme, despite involving local management and trade. Only one smallholder declared that the *pinhão* trade in his propriety was certified by an NGO under a co-management scheme. The same participant is also granted with one project involving Payment for Environmental Services (PES) to conserve araucaria remnants in areas beyond the Legal Reserve within his property. Four participants use their properties for tourism purposes involving araucaria (i.e. ecotourism). Among these four interviewees, two of them have co-management partnerships with international stakeholders and NGOs to promote sustainable tourism in the Araucaria Forest region.

Traditional Ecological Knowledge about araucaria management and ethnovarieties

Sixty-one participants (63%) said that Araucaria Forest cover around the property (if applicable) expanded in the last decades due to: (i) the creation of Protected Areas (N = 33); (ii) restrictive legislation (N = 18), consequently sawmills' interdiction for using native and threatened species (N = 5); (iii) community participation in reforestation (N = 9); and (iv) increased dispersal by local fauna (N = 6). The remaining 35 participants informed that Araucaria Forest cover has been decreasing, mainly due to: (i) seedling suppression, known as "*roçadas*" (N = 22); or (ii) illegal logging (N = 18). We also found interviewees describing negative impacts from (iii) pesticides (N = 1); (iv) severe legislation (N = 1); and (v) ecological competition with *Pinus sp.* (N = 1). We identified 23 local names for types (ethnovarieties) based on 320 citations from all participants. These ethnovarieties were described by local people (i.e. smallholders and/or *pinhão* extractors) according to the ripening periods of *pinhão* seeds produced by female araucarias. The five most-cited local varieties were: (i) "*Macaco*" (N = 81 citations); (ii) "*Cajuvá*" (N = 80 citations); (iii) "*Comum*" (N = 48 citations); (iv) "*Do Cedo*" (N = 31 citations); and (v) "*25 de Março*" (N = 16 citations). Most participants cited three ethnovarieties (52.5%) and ~25% of them mentioned four different ethnovarieties. Ethnovarieties described by the participants were said to develop in different moments during the year indicating *pinhão* production throughout the entire year.

Socio-ecological benefits and risks of both alternative models for Araucaria Forest Systems

The benefits and risks of adopting a top-down or bottom-up strategy for Araucaria Forest System involve different ecological, social, economic, and cultural dimensions according to the interviews and the literature review (Fig. 3; Table 1). Top-down conservation models promote benefits towards the target species (in this case araucaria) and its surrounding fauna and flora; the biodiversity maintenance; and provides ecosystem services, such as provisioning (food with *pinhão* production); support (pollination; nutrient cycling); regulation (carbon sequestration; alternative food resource for Araucaria Forest fauna); and cultural (heritage value, regional symbols, ecotourism). Biodiversity and ecosystem services may be indirectly enhanced by this model, thus favoring human well-being. However, restrictive top-down models (such as Strictly Protected areas or excessive restrictive legislation) may create: (i) barriers between human groups and the target preservation priority; (ii) the loss of TEK and socio-ecological resilience; (iii) fragility to external stressors, such as climate change.

The most promising benefits of bottom-up co-management are: (i) sustainable *pinhão* trade; (ii) sustainable tourism; (iii) Payment for Environmental Services programs; (iv) potential conservation of Araucaria Forest remnants within rural properties; and (v) possible recovery and expansion of Araucaria Forests. By incorporating these initiatives with local people, they may also stimulate local engagement in surveillance, conservation, and maintenance of biodiversity. These benefits are interconnected between local groups and Araucaria Forest, enhancing the long-term resilience and conservation of the Araucaria Forest System. The risks of adopting bottom-up co-management schemes for Araucaria Forest Systems may be related to: (i) psychological barriers between local people and environmental agencies due to the memory of historical excessive enforcement – an example is a practice known as '*roçadas*', which consists in the removal of araucaria juveniles to avoid future legal restrictions on land use (Adan et al., 2016) –; (ii) the potential overexploitation of araucaria resources within private areas, such as illegal cutting, timber exploitation, and deforestation (Orellana and Vanclay, 2018); and (iii) possible poor communication between local people, stakeholders, and environmental agencies (Freitas et al., 2020). However, negative co-management experiences are more likely to be corrected by positive innovations from local peoples, since their TEK and the intrinsic body of knowledge through generations might allow them to maintain feedbacks stronger, responding faster to external changes, enhancing adaptability, and transformability of the system (as shown by Berkes et al., 2000).

Two alternative models of Araucaria Forest conservation: top-down with restrictive use, and bottom-up with co-management schemes

Two alternative conservation models of Araucaria SES showed different feedbacks and dynamics (Fig. 4; Table S3). The top-down restrictive scheme contributed to increasing forest resilience to human disturbances. This happens because '*deforestation*' and '*resource overexploitation*' lead to more enforcement and '*forest protection*' (restrictive measures) by managers to maintain '*forest cover*'. With more forest cover, resource overexploitation is expected to decrease, relative to the overall forest abundance, reducing the perceptions of overexploitation by managers, and leading to less restrictive measures. In this sense, we identified that restrictive measures are created as a response to human disturbances (i.e. *deforestation* or *resource overexploitation*), resulting in a negative feedback loop that dampens forest loss (see Fig. 4) and partly maintains the conservation purpose. The top-down scheme, however, might not guarantee resilience for the entire system to other types of disturbances, such as extreme weather events due to climate change, mainly because the loss of traditional management may reduce the functional diversity of araucaria populations (Table 1; Adan et al., 2016), and consequently the forests' adaptive capacity in the face of unexpected events (Elmqvist et al., 2003). Hence, the top-down scheme completely disrupts the historical human-plant interaction of the AFS that made this system resilient for millennia. In contrast, the bottom-up conservation scheme showed a distinct feedback loop (Fig. 4). In this case, a self-reinforcing (positive) feedback loop emerged in the system, because '*Traditional Ecological Knowledge (TEK)*' provides opportunities for '*collaborative management*', which allows '*forest cover*' to persist and potentially expand. With more forest cover, TEK is expected to expand as well, promoting co-management that enhances the general ecological resilience of the forest (to all sorts of unexpected disturbances), because local management enhances the functional diversity of araucaria populations (Table 1; Adan et al., 2016). The positive feedback loop we identified has therefore the potential to strengthen the ecological resilience of the whole Araucaria SES and to promote the system's expansion beyond its current limits.

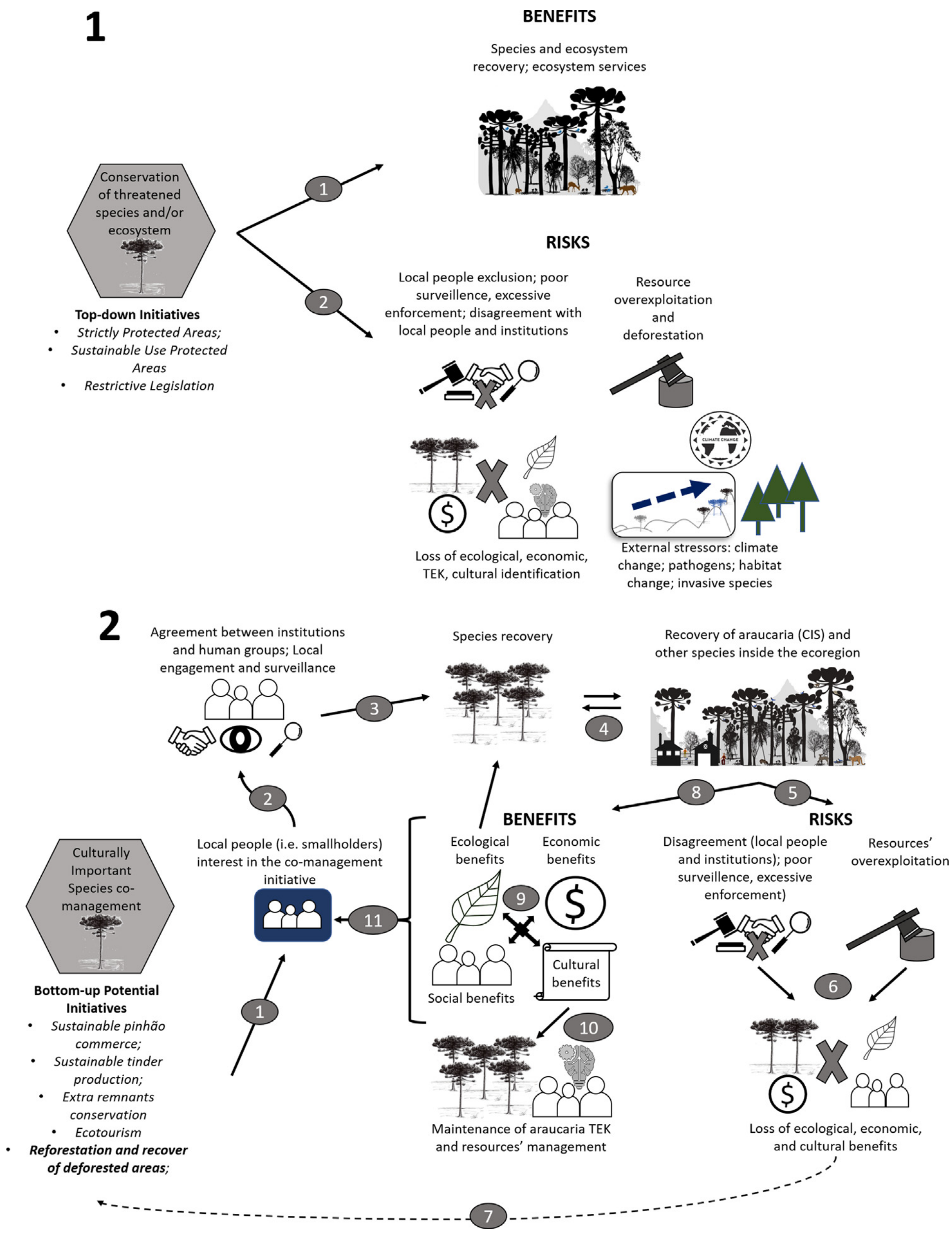


Fig. 3. Flow chart of benefits and risks (inspired by Freitas et al., 2020) of distinct conservation strategies. Arrows represent the expected outcomes of every step in the flow charts. **1. Top-down strategies for *Araucaria angustifolia* (araucaria) preservation.** As the main conservation strategy, top-down policies, such as the maintenance or creation of Strictly Protected, neglect the historical human-plant interaction in the Araucaria Forest System. These policies **(1)** maintain the ecological resilience of the forest ecosystem and provide ecosystem services (indirect benefits for human groups), but **(2)** may fail due to barriers upon traditional people who use, manage, and promote the socio-ecological resilience of the system, leading to the loss of TEK; increases in overexploitation and deforestation pressures; and reduced resilience to external stressors, such as climate change, pathogens, and invasive species. **2. Bottom-up conservation initiatives for araucaria as a Cultural Important Species (CIS) under co-management**. Because araucaria is a culturally important species for local people, **(1)** they will likely feel stimulated to engage in co-management initiatives focusing on this species; **(2)** we should consequently expect high compliance and local surveillance local people; **(3)** this human-plant interaction which will likely favor the conservation of araucaria populations and **(4)** benefit other species co-existing in the Araucaria Forest, and the ecosystem as a whole. There are both benefits and risks that could be expected from this co-management approach. The risks **(5)** of this initiative may be related to the potential fragile arrangement between local people and institutions (e.g. environmental agencies, Non-Governmental Organizations, private sector and/or stakeholders); inadequate surveillance of the co-management initiative; and/or the excessive institutional enforcement. Another risk is the increase of illegal cutting (i.e. resources' overexploitation, juveniles' suppression, and/or non-sustainable timber production). Such negative consequences **(6)** will possibly affect ecological (i.e. ecosystem degradation), economic (i.e. less *pinhão* trade, loss of payments or compensations for environmental services; less ecotourism), and cultural (detachment from local people, loss of traditional knowledge) aspects. A potential way to circumvent those problems (e.g. increased deforestation) could be **(7)** alternative co-management initiatives targeting forest recovery or recuperation of degraded areas (dashed arrow). The positive scenario **(8)**, however, could bring ecological (maintenance of the ecosystem); economic (via Payment for Environmental Services, sustainable *pinhão* trade, ecotourism); social and cultural benefits (i.e. local engagement; maintenance of the Traditional Ecological Knowledge of araucaria and its ethnovarieties, and araucaria resources' management). All of these positive consequences are interconnected **(9)** and could finally allow a more resilient and cyclical stable state **(10)** of the entire eco-socio-economic system of Araucaria Forests, besides acting as an alternative to the mainstream conservation strategy (i.e. the maintenance of exclusionary Protected Areas via top-down policies).

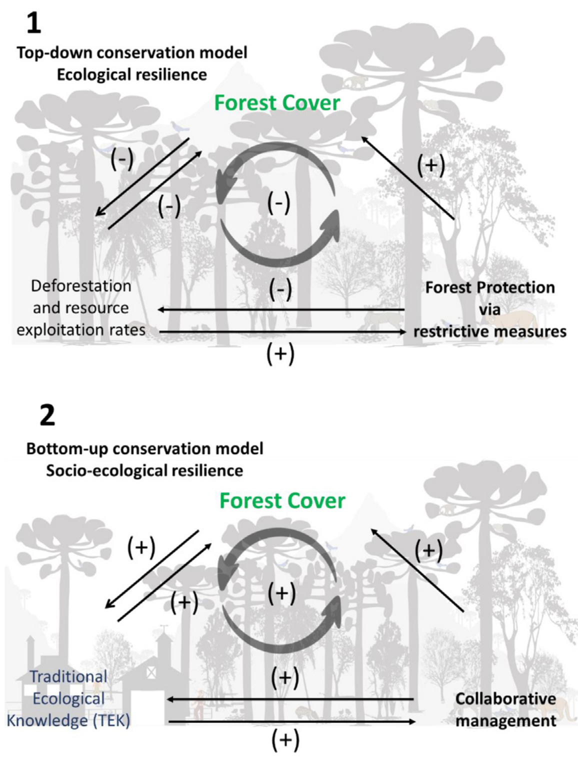


Fig. 4. The schematic top-down and bottom-up conservation models of Araucaria Forest systems are self-organized in contrasting ways, with different feedbacks. Solid lines represent positive/negative effects. Cycle schemes (gray shaded) represent the feedback loop, its direction (i.e. counter-clockwise) and its result: negative/buffer effect or positive/self-reinforcing state. **1. Schematic representation of the interactions involved in top-down policies, such as Strictly Protected Areas.** This scheme improves only a portion of the target ecosystem, neglecting potential socio-ecological interactions (i.e. local people). This classical conservationist approach creates a buffer feedback, i.e. it sustains the current state. Excessive resource exploitation or deforestation generates protective measures that benefit forest cover. However, a forest protected by top-down measures may not completely avoid these disturbances (e.g. deforestation and overexploitation) and might not contribute to other external stressors, such as climate change. They also reduce the benefits for local peoples, who are virtually excluded from the system. **2. Schematic representation of the interactions produced by bottom-up policies.** Independently from restrictive measures, this schematic socio-ecological system indicates an increase in the system's resilience, due to a self-reinforcing mechanism that promotes araucaria forest expansion. Hence, by incorporating TEK and co-management initiatives, this scheme increases the general resilience of the social-ecological system. Note: our conceptual model is not mutually exclusive, both top-down and bottom-up strategies co-occur within AFS and contribute to maintaining native forest remnants.

DISCUSSION

Our findings reveal that Araucaria Forest Systems in southern South America might be losing resilience due to a long-term top-down restrictive management scheme that makes the system less adapted to all sorts of disturbances. Partly because this social-ecological system depends on TEK, which is currently being lost as restrictive measures disrupt an ancient human-nature interaction. However, our study reveals an alternative perspective on how to maintain the general resilience of Araucaria Forest Systems by stimulating TEK production through a collaborative management scheme. We have shown that bottom-up co-management may self-reinforce and benefit the resilience of araucaria forests and thus provide a possible solution for the conservation dilemma that has been threatening this ecosystem. Co-management initiatives may effectively incorporate the principles of resilience-thinking: management of feedbacks; maintenance of ecological diversity; and broad participation of different actors (Folke et al., 2005, 2010). Strengthening local actors and their roles in governance is particularly effective when compared to restrictive and exclusionary conservation strategies, such as Strictly Protected Areas with excessive top-down enforcement. We believe our findings offer an opportunity to generate optimistic bottom-up pathways towards an efficient, inclusive, and well-articulated conservation strategy that could self-reinforces the resilience of the Araucaria Forest System. By shifting from a top-down to a bottom-up co-management scheme that includes local actors together with existing institutions in the governance process, the AFS could develop transformability and adaptability, further enhancing its social-ecological resilience (see Folke et al., 2005, 2010; Biggs et al., 2012; Bennet et al., 2016). Because similar ecosystems with culturally important plant species are also undergoing the same conservation dilemma, we believe that our findings could be useful in other contexts. Such innovative and collaborative systems could potentially develop to become another global *brightspot* example, where the natural and cultural capitals are preserved by bottom-up arrangements, inspiring societies worldwide (Bennett et al., 2016).

Although the top-down strategy has proven useful to maintain araucaria forests resilient to logging and other human degrading activities via a negative feedback loop (Fig. 4), this strategy has not been sufficient to maintain the entire system in the long run. Since the historical logging overexploitation in the 19th century, and later, the inclusion of araucaria as "Critically Endangered" by IUCN (Thomas et al., 2013), the creation/maintenance of top-down Protected Areas became the cornerstone of its conservation (Zechini et al. 2018). Protected Areas aim to curb anthropogenic disturbances in natural ecosystems and halt the loss of biodiversity (Geldmann et al., 2019; Wiens et al., 2011), but might fail to prevent the extinction of several species in the long-term due to climate change (Ferro et al., 2014), as well to anthropogenic disturbances (e.g., invasive species; poaching; land use; loss of genetic diversity; Laurance, 2013); and to potentially promote socio-economic benefits (given poor governance or regional conflicts; Laurance et al., 2012). In southern Brazil, traditional land management systems protect the genetic diversity of araucaria populations, thus contributing to the species conservation and the safeguarding of the SES (Reis et al., 2014; Mello and Peroni, 2015; Adan et al., 2016; Zechini et al., 2018). As a result, top-down conservation strategies are insufficient to conserve a cultural landscape (Mello and Peroni, 2015) because it reduces the systems' adaptive capacity, as well as the participation of different actors in environmental governance; all requisites for social-ecological resilience (Folke et al., 2010; de Vos et al., 2016; Musavengane, 2019).

The feedback dynamics of a bottom-up co-management strategy has the potential to enhance the systemic resilience of AFS as well as other Social-Ecological Systems, because it promotes adaptability through TEK production (Berkes et al., 2000), and because it recognizes that transformability into participatory governance is necessary, as human-nature has shaped Araucaria Forest landscapes over millennia (Reis et al., 2014). Moreover, it enhances connectivity, because different actors are connected in the system (e.g. NGOs; stakeholders; local groups; governments). Also, it retains functional redundancy, *i.e.* if one actor is removed from the system the system itself remains resilient to the disturbance because of the different players with the same functions. We also found support for the notion that a bottom-up co-management strategy can enhance the resilience of AFS not only to human disturbances but also to different kinds of threats, such as extreme weather events (Folke et al., 2010). One reason is that co-management increases the functional diversity of araucaria tree populations, especially due to use and management (Adan et al., 2016; Tagliari and Peroni, 2018; Quinteiro et al., 2019), and consequently the adaptive capacity of the forest to unexpected disturbances (Elmqvist et al., 2003). As a result, co-management generates a positive feedback loop that strengthens forest resilience as well as sociocultural resilience. The Araucaria Forest is an example of a self-reinforcing system, where in the past human-plant interaction was responsible for the forest expansion beyond its climatic niche (Robinson et al., 2018).

Sühs et al. (2018) showed that the maintenance of araucaria mature trees together with traditional land management promotes Araucaria Forest expansion, sapling species richness and abundance, together with the preservation of grasslands in southern Brazil. The authors argue that a maximal regional diversity of the plant communities can be achieved by a balance between preserved forest areas and traditional management practices (Sühs et al., 2018). Reis et al. (2018) also showed that management systems within the Araucaria Forest, such as the "*caívas*" and "*faxinais*", maintain landscapes with productive forest fragments, thus favoring araucaria conservation and human well-being. Furthermore, this system highly depends on the cultural and economic valuation of *pinhão* (Reis et al., 2018). The opportunity to increase profits from araucaria remnants could assure the long-term sustainability of co-management initiatives (Pomeroy and Berkes, 1997). The broader participation of different actors in environmental governance is within the basis of co-management initiatives (see Freitas et al., 2020). Hence, co-management initiatives targeting the *Araucaria angustifolia* can represent a valuable solution for the ongoing conservation dilemma.

CONCLUSION

Re-evaluating the araucaria conservation dilemma

Our bottom-up conceptual model was directly linked to a specific social group: the smallholders along the AFS, who possibly encompass the majority of AFS native remnants under their Legal Reserves protected areas (Bittencourt and Sebbenn, 2009; Metzger et al., 2019). Other social groups still influence and manage this system, such as indigenous peoples, who were co-responsible for the transformation and expansion of the system in the past (Robinson et al., 2018), and remain as essential partners for developing a co-management scheme. Although we could not incorporate indigenous peoples in our analysis, they also apply to our conceptual model as major TEK holders. It is important to recognize that the AFS is also composed of a mosaic of landowners, agricultural enterprises, timber and cellulose companies, where native remnants are still protected by top-down management, such as in Strictly Protection Conservation Units and Legal Reserves. Therefore, our conceptual models are not mutually exclusive, and both top-down and bottom-up strategies may co-occur within AFS and contribute to maintaining native forest remnants resilient in the face of global changes.

Araucaria Forest Systems are a heritage, left by past indigenous societies that once lived in the region (Reis et al., 2014; Robinson et al., 2018), and that now represents a valuable asset for local human populations (Mello and Peroni, 2015; Adan et al., 2016; Tagliari and Peroni, 2018; Quinteiro et al., 2019). Our findings indicate that this heritage might be at risk in the long-term for future generations. The collaborative management strategy between local peoples and other institutions interested in the conservation of these ancient and endemic forests is necessary as an alternative strategy to maintain this socio-ecological system. However, legal aspects may remove local people from decision-making and potentially produce antagonistic actions due to restrictive conservation measures, such as seedling suppression (Adan et al., 2016; Tagliari and Peroni 2018; Quinteiro et al., 2019) or timber illegal exploitation (Schneider et al., 2018). This problematic may engender what is known as the 'Environmental Psychologic Barrier', where local people tend to avoid effective action to improve/conserve their surrounding environment, even if they perceive that these actions bring biodiversity losses and negative impacts to their lives, such as loss of life quality and food security (Tam and Chan, 2017). Still, other co-management initiatives of culturally important species in Brazil showed positive outcomes by maintaining the plant-human interaction, such as those involving *Hevea brasiliensis* and *Bertholletia excelsa* ("*rubber tree*" and "*Brazil nut tree*", respectively) in the Brazilian Amazon, and *Rumohra adiantiformis* ("*samambaia-preta*") in southern Brazil (De Souza et al., 2006; Gomes et al., 2018). Co-management programs with these species largely contributed to maintaining the economic livelihoods and Traditional Ecological Knowledge of local smallholders and people from indigenous and local communities (e.g. indigenous people, "*ribeirinhos*", and/or "*caiçaras*"; De Souza et al., 2006; Gomes et al., 2018). Similarly, the conservation of the Araucaria Forest System depends on maintaining TEK and promoting collaborative management initiatives, because bottom-up conservation strategies are more likely to produce the transformations that the system needs to persist in the uncertain future. By incorporating all actors of this socio-ecological system, resilience is reinforced towards expansion, maintenance of TEK, and participatory systemic socio-ecological conservation.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR'S CONTRIBUTION

MMT conceived the main idea, drafted the manuscript, analyzed interviews' data, and did the main literature review. GDB drafted the manuscript and did the literature review. CL contributed to the literature review and developed the main structure of the article. BF brought valuable insights that transformed the purpose of this study. CF reviewed the early versions, suggested main changes in the structure of the manuscript. JB contributed to the draft evaluation, improved the interview questions, and analyzed the data. GV contributed with the early versions of the manuscript and insights about potential knowledge-gaps. NP contributed to draft development, literature review, insights about knowledge-gaps, improved the interview questions, reviewed the early versions, and project financing. All authors contributed critically to the drafts and gave final approval for publication.

DATA AVAILABILITY STATEMENT

This manuscript is part of an ongoing Ph.D. thesis. The information gathered in the ethnoecological surveys will not be able to share until the publication of another specific chapter. However, as a manuscript based on the literature review (already published elsewhere) and complemented with the ethnoecological information used in the questionnaire (see details in Supplementary File Tables S1, S2, S3), the readers may find the core information used in this manuscript.

ACKNOWLEDGMENTS

MMT thanks all local people interviewed between 2018 and 2019 who contributed with their knowledge about araucaria, the cultural landscape, and the challenges smallholders face in Brazil. The authors would like to thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES/Brazil; Finance Code 001) for the Ph.D. scholarship for MMT and GDB. CL thanks CAPES for the post-doctoral fellowship (nº 88887.474568/2020). NP thanks CNPq for the productivity scholarship (Process 310443/2015-6). CTF thanks the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) for the post-doctoral fellowship (Process nº 2019/15550-2). JAB is supported by the São Paulo Research Foundation (FAPESP) postdoctoral fellowship grants 2018-05970-1 and 2019-11901-5. This study is dedicated to Estelamaris and Patrick.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.pecon.2021.03.002.

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