Environmental Science and Policy 94 (2019) 39–48

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

Diversifying knowledge governance for climate adaptation in protected areas in Colombia

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ARTICLE INFO

Keywords:
Science-policy interface
Knowledge governance
Climate change
Protected areas management
Civic epistemology
Diverse forms of knowledge

ABSTRACT

Protected areas face many threats, including the observed and projected impacts of climate change, yet there is little evidence that adaptation strategies are providing comprehensive solutions to deal with ecological transformation due to changing climates. In this article we explore whether, how and to what extent the governance of knowledge helps or hinders managerial change towards more proactive climate adaptation. We applied a knowledge governance framework that addresses social and cultural dimensions of environmental decision-making, alongside the institutional arrangements that support particular knowledge-based relationships, to document the knowledge-based processes in place for managing protected areas under uncertain climate change in Colombia. We found that the results of scientific experimentation and modelling (mainly in the natural sciences) are often stated as the preferred source of knowledge to inform decision making, forming a dominant narrative that climate adaptation can and should be driven by scientific and technical information. However, institutional arrangements in practice were typically more diverse in the knowledge sources that contribute to protected area policy and practice. This indicates a significant mis-match between the desired knowledge base for climate adaptation governance, and the actual knowledge processes that underpin effective planning. We propose that understanding institutional arrangements that shape adaptation decision contexts can help to address barriers for using climate information effectively, including understanding its limitations. It can also help managers identify opportunities to draw on existing diverse and rich knowledge systems to support the institutional transformations needed to enable strategic planning and management for effective climate adaptation.

1. Introduction

Protected areas are central for conservation of biodiversity (Rands et al., 2010). In these complex social-ecological systems multiple issues and stakeholders interact across scales, generating complex governance challenges (Cumming and Allen, 2017). The high uncertainty associated with climate change and other drivers of global change influences how protected area managers plan and manage biodiversity (Schliep et al., 2008; Lemieux and Scott, 2011; Rannow, 2014), raising questions about the effectiveness of current conservation strategies and governance to address climate adaptation in conservation processes (Wyborn et al., 2016; Colloff et al., 2017). A traditional approach to increasing the effectiveness of conservation has been to direct greater effort into connecting scientific information with decision making (Colloff et al., 2017). Despite many efforts to improve biodiversity and climate information (Cornell et al., 2013; Beier et al., 2016; Cvitanovic et al., 2016), it is becoming increasingly evident that science alone may not be enough to inform policies that anticipate change (van Kerkhoff and Lebel, 2006v; Laurance et al., 2012; Kirchhoff et al., 2013; Fernández, 2016). Future-oriented conservation implies ideas of anticipating change and collaboration (Wyborn et al., 2016; van Kerkhoff et al., 2018v), that may not be well-served by traditional, science-based approaches. Following Eriksen et al. (2015), we propose that part of the challenge of implementing climate adaptation in conservation may arise from governance arrangements that focus mainly on the scientific technical aspects of climate change, rather than embracing the social and political processes and having collaborative approaches to incorporate multiple adaptation 'knowledges' that enable change.

In this study we sought to explore the role of science in the complex decision-making context of policy, planning and management tasked with preparing protected areas for future climate change. There are many social processes that frame how science informs policies, defining which knowledge provides legitimacy to governance and decision making processes. The research was conducted as a case study, to

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https://doi.org/10.1016/j.envsci.2019.01.004
Received 4 July 2018; Received in revised form 9 January 2019; Accepted 9 January 2019

understand the governance arrangements that structure relationships between knowledge and practice (Jasanoff, 2005). These arrangements include the formal and informal rules on how researchers and decision makers interact; how they perceive and value different kinds of knowledge; and how managers address uncertainty when applying certain type of knowledge (McNie et al., 2016). We examined these connections from a decision-making perspective in a collaborative project (Future-proofing Conservation-FPC), based in Colombia. We adapted the knowledge governance framework of van Kerkhoff and Pilbeam (2017) to understand the social, cultural and institutional structures that underpinned the use of scientific and technical climate information in adaptation decision-making in conservation. Our research questions were: 1) which forms of knowledge and information related to climate change and ecosystem services are used for planning and management in protected areas in Colombia? And 2) how can knowledge management be enhanced for strategic thinking and decision making so that Colombian protected areas can continue to provide benefits under climate change? We report here on applying the conceptual framework, insights generated by the data and the role of this research in informing conservation policy, planning and management of protected areas under climate change.

1.1. Conceptual framework

Knowledge-based processes are socially complex and subject to intricate governance structures (Chong et al., 2005), defining which knowledge providers are sought, what knowledge processes are considered legitimate, valid and relevant to inform policies and decisions, and how knowledge-based inputs are evaluated. Knowledge governance is defined as "the formal and informal rules and conventions that shape the ways we conduct or engage in knowledge processes, such as creating new knowledge, sharing or protecting knowledge, accessing it and applying or using it" (van Kerkhoff and Pilbeam, 2017:30). Knowledge management refers to the day-to-day actions of using, sharing and managing information, and is shaped by knowledge governance arrangements (Gerritsen et al., 2013). However, while knowledge management activities are often very apparent, knowledge governance arrangements are often poorly understood, taken for granted or invisible to agents dealing with complex, socio-political and technical issues such as environmental management or climate change. The proposition for knowledge governance, as applied here and explained by van Kerkhoff and Pilbeam (2017:32), is that when stakeholders recognize the structures that shape knowledge-based processes, including the socio-political and cultural contexts where decisions are made, it will be easier for them to develop effective knowledge management strategies that enable transformative adaptation (Eriksen et al., 2015). This approach can support participants to identify interventions that align with, or challenge, societal norms, to recognize political contestation over knowledge, and to demonstrate the different perceptions of reality and visions of the future that managers, planners, policy makers and scientists may have (Fernández, 2016). This can enable more targeted strategies for overcoming social and institutional barriers to change, and ultimately more effective environmental decision-making for climate adaptation.

We visualize these interactions as a three-layer model, illustrated in Fig. 1 (van Kerkhoff and Pilbeam, 2017v). The upper socio-cultural frame of civic epistemology denotes the social, cultural and political norms that underpin public expectations about how the State and society use knowledge in decision-making (Jasanoff, 2005). Civic epistemology identifies deep-seated patterns that shape how society governs knowledge based-processes, including formal and informal rules, and interactions of individuals; individuals are recognized as active agents in the process. The intermediate layer of institutional knowledge systems, building on Cash et al. (2003), represents institutional arrangements that connect knowledge with decision making and action, including criteria for the credibility, legitimacy and salience of knowledge. Institutional arrangements or structures refers to the different rules, dynamics, roles and interactions that shape decision-making processes (van Kerkhoff and Pilbeam, 2017v). Both civic epistemology and knowledge systems influence the central layer of 'interventions' for knowledge management. These interventions are deliberate actions to manage or change knowledge-based processes within these broader social structures; they may comply with or contest the institutional arrangements of existing knowledge systems, or the social and cultural norms of civic epistemology. Knowledge management responses feed back to the interventions and knowledge systems, re-informing civic epistemology. Using this knowledge governance framework can help to explore current knowledge-based management practices for climate adaptation, and situate them in their broader institutional, social and political context.

1.2. Case study

Colombia is one of the most biodiverse countries in the world. Globally, Colombia is ranked the 33rd most vulnerable country in the Climate Risk Index (Kreft et al., 2016) and has experienced extreme climate events that have impacted rural and urban livelihoods and conservation (IDEAM et al., 2017). Protected areas are managed via a national network known as SINAP (DNP, 2010) which provides managerial instruments to multiple stakeholders at different governance levels. PNN's role is to coordinate stakeholders and sectors to implement policies and programmes to support and strengthen the network of protected areas (SINAP) and the National Environmental System (SINA). The SINA is a set of guidelines, resources and programs for policy implementation (Law 99–1993), including establishment and management of protected areas, promoting scientific collaboration and informing policy makers (Andrade and Londono, 2016; De Pinto et al., 2017; Sierra et al., 2017). PNN, responsible for managing the protected areas system, has four main institutional strategies to guide their projects and interventions towards a protected areas national system that is complete, effectively managed and representative of Colombia's biodiversity:

1) Prevention of biodiversity loss: guidelines to incorporate surveillance and control actions in the management plans to protect biodiversity and reduce threats.
2) Sustainable systems for conservation: to promote participatory planning based on sustainable practices with local communities, and activities for biodiversity conservation.
3) Environmental education: to promote education to enable the provision of information for participatory decision-making processes in protected areas.
4) Research: for management and decision making and as a contribution to fulfil the conservation objectives for natural, cultural and historical values.

This project was a partnership between researchers (The Australian National University-ANU, The Commonwealth Scientific and Industrial Research Organisation-CSIRO, Luc Hoffmann Institute-LHI), advocacy partners (World Wildlife Fund Colombia-WWFC), practitioners from the Colombian National Parks Agency (Parques Nacionales Naturales Colombia-PNN), and conservation advisers (Equilibrium Research). The research team co-produced a methodology, goals, processes and activities for thinking and learning to facilitate decision-making under uncertainty about the impacts of climate change (van Kerkhoff et al., 2018v). The aim of the broader project was to facilitate understanding climate-induced transformation as a governance challenge, to enable individuals and organisations to anticipate and prepare for future change. The study reported in this article was conducted in the preliminary stages of the project to develop a systematic and shared understanding of the decision-making context, and the role of scientific and technical knowledge in existing protected area governance.

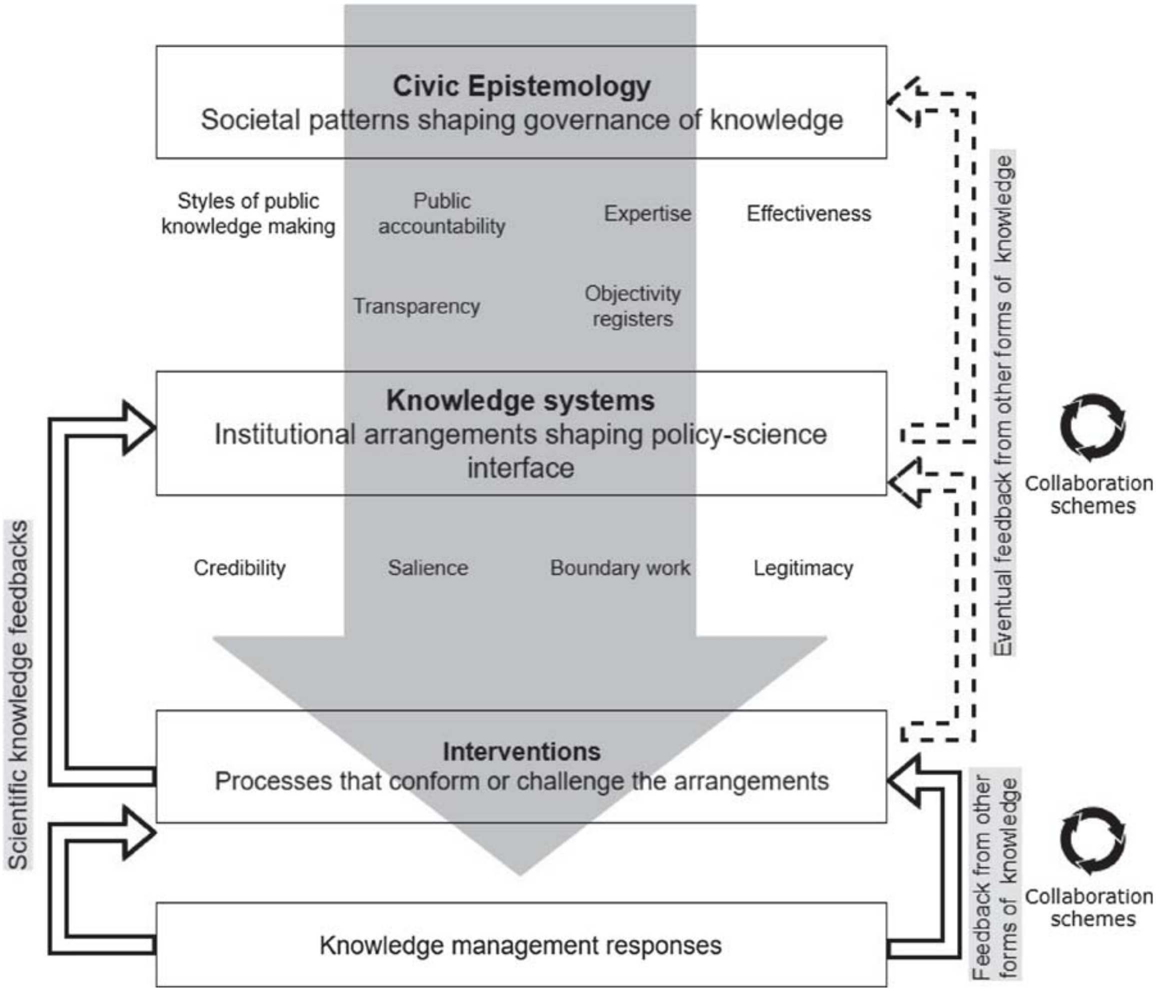

Fig. 1. Knowledge governance framework applied in the research. Civic epistemology and knowledge systems provide strong input shaping the interventions. Some forms of knowledge (e.g. scientific, bold arrow) provide stronger feedback to the system, but other forms of knowledge (dotted arrow) may provide feedback over time. Adapted from van Kerkhoff & Pilbeam (2017).

2. Methods

We conducted a preliminary review of policy documents to identify the formal management structures and to note any specific references to information or knowledge management. We then applied a qualitative interview-based method to document current knowledge governance processes in protected areas management in Colombia. Key stakeholders were purposively sampled to share their experience of knowledge-based processes with regard to climate change. Interviews examined institutional incentives or barriers to effective knowledge sharing and application such as gaps in chains of communication, and possible actions for more efficient and cost-effective decision making for natural resources management. In consultation with WWFC and PNN, two case study sites were selected with contrasting management goals, and ongoing climate-related projects: the Amazon Piedmont (Churumbelos and Alto Fragua National Parks), and the Coffee Growing Region (hereafter CGR, specifically Otún Quimbaya Flora and Fauna Sanctuary).We conducted 28 semi-structured interviews to document knowledge governance processes. The criteria for the sample included actors who have an active role in the protected areas planning/management, those who have an active role with climate/environmental services information (that is, they produce, maintain or use it) and those with roles in knowledge-based processes for decision-making with a focus on climate and ecosystem services information. Our partners facilitated and provided appropriate cultural guidance and introductions within the Colombian context. Participants included PNN staff from the three levels of management: Central level in Bogota, Regional and Local level (cities of Mocoa in Putumayo, and Pereira in Risaralda), staff from WWFC, staff from a Regional Environmental Authority, and from a university.

This project was approved by ANU Human Research Ethics Committee 2018/486. The interview guide consisted of 22 open-ended questions, following the knowledge governance framework (Fig. 1) to document how knowledge governance shaped knowledge generation, access, sharing, and management actions. Interviews were conducted by CM in Spanish, lasting 30–60 minutes, and then recorded and transcribed for analysis using NVivo 11 software. The analyses consisted of thematic coding, including *contextual nodes* to map responses to the questions and six *research nodes* around the use of climate information in decision making and planning. Table 1 indicates how often a theme was mentioned and coded in the interviews.

3. Results

Our review of policy documents indicated that protected areas management in Colombia follows a hierarchical structure, with a Central level at PNN setting the rules and guidelines for territorial and local level management. These institutional structures establish the directions for collecting, organising and using information in the planning process (known in the Colombian context as the “planning route”). It also establishes guidelines for collaboration and communication with other stakeholders. In general, the planning route for

Table 1
Interview analysis from the interviews with key stakeholders engaged in Colombian protected areas management and climate change. Sources denote the number of interviews that responded the question, references refers to how frequently a thematic was mentioned.

Research question	Analytical codes	Descriptive codes	Sources	References
1) Which forms of knowledge and information related to climate change and ecosystem services are used for planning and management in protected areas in Colombia?	Civic epistemology: styles of decision making, accountability, transparency etc.	Diverse forms of knowledge (preferred form of knowledge for planning)	28	31
	Knowledge systems: salience, credibility, legitimacy; institutional rules (formal, informal)	Planning route (how information is used for planning)	28	35
		Information characteristics (accessibility, usability, providers)	28	84
2) How can knowledge management be enhanced for strategic thinking and decision making so that Colombian protected areas can continue to provide benefits under climate change?	Interventions: current strategies; limitations; barriers; opportunities for change	Learning (processes)	27	27
		Connections between knowledge, rules and values in decision making	19	19
		Visions of the future	28	28

State managed protected areas in Colombia follows a logical model with a "reactive" approach, identifying pressures to natural systems (human activities or natural threats) to define conservation management options (Diaz Leguizamon, 2016). Although all management plans follow this approach, PNN has been adapting the rules to allow a more proactive response at local levels, emphasising environmental diagnosis, strategies and management according to local conditions. Here we present examples from Colombian protected areas management explaining the preferred type of knowledge used in decision making at different levels of management. We also explain the different connections between management level across scales, the differences between the study sites, and how this reflects the three layers of the knowledge governance framework. We show patterns in perceptions of knowledge; barriers in using information for decision-making; governance arrangements preventing effective knowledge management for future planning; and suggest some potential feedbacks from the management responses (Fig. 1). We do not claim that the results presented here fully explain the complex multilevel/multiscale context of Colombian protected areas. As explained in Section 1.1., we want to demonstrate the value of applying this framework to help to address current challenges for institutional change as part of a broader strategy towards transformation of conservation policy, planning and management (see van Kerkhoff et al. (2018). The extracts below, translated by CM, are presented as examples; quotes with "C_#" refers to interviews at Central level, while "L_#" come from Local level interviews.

3.1. Knowledge governance arrangements in Colombian protected areas at the Central level

Our data indicate that the dominant style of public knowledge for decision making in conservation and protected areas at the Central management level in Colombia follows a formal scientific narrative (Table 2). This knowledge, provided by academic experts, represents agreed social objectives for conservation. While there is often a substantive role for this information, in terms of 'diagnoses' of what needs to be done, or prioritised, equally important was the political role of scientific information (quote C_01 in Table 2). Science supports lobbying where trade-offs and resource allocations are arranged, demonstrating that scientific knowledge influences policy making at national level, but also that the informative aspect of this influence ('diagnosis') cannot be easily separated from the political aspects ('lobbying'), where social and cultural norms accept science as authoritative. Scientific information, especially from biodiversity and environmental services, provides not just guidance but credibility for PNN, which supports accountability and demonstrates the importance of protected areas for the country. For example, research that provided economic valuation of water provision from protected areas to national GDP (quote C_02 in Table 2). This confirms a tendency to validate current management with scientific information, where formal expertise is a respected basis for public-knowledge processes.

We expected to see this same approach for managing protected areas under climate change. Protected area managers already deal with several human-induced ecological transformations (deforestation, mining, etc.) and in practice they tend to rely on expert-driven information such as biodiversity inventories or changes in extent of deforestation. But how effective could this be when using uncertain climate projections or modelling? Participants noted an apparent disconnect between climate information and conservation objectives in the protected areas: *climate change was included into the management and operation plans, but it was not linked to the conservation objectives of the areas* (C_03). Although climate change could elicit a new type of strategic thinking, and has clear implications for conservation objectives, climate induced ecological transformation is not yet used as a framing question for decision making. Participants recognize this and suggested some key issues that might help, as for example having more clarity on the problem they want to address before collecting and using climatic information, as well as capacity building around climate change concepts. Some ongoing initiatives could help to achieve this: *we are creating a climate baseline [for each park] so that managers can use this information for their strategies, and that they perceive the information is useful and take ownership of it* (C_05) and: *at the administrative and technical level there is a lack of training in these issues…we need to create strategies for the different instances, for the decision makers and for the different levels of knowledge* (C_05). They also recognize that a better understanding of ecological transformation is critical for improving strategic planning under climate change: *we are in a changing world, management plans would need to have those different perspectives of time and try to promote the generation of land use scenarios* (C_13). Having said that, participants also recognized that they have sufficient climate information but the challenge of using it in conservation management relies on the difficulties in analysing, reviewing and understanding it: *we can no longer say that we don't have information, much of that information was stored and nobody is using it…we need to evaluate what we have, to better understand what we need for future management* (C_03). To address this, they emphasized the need to build capacities to better understand, use and analyse climate information for making decisions, have better collaboration with researchers to support translating climate information, and ensure knowledge producers and end-users are involved in decision making: *It is a matter of capacities, skills, strengthening communication among the three levels…[the protected] area recognizing that is immersed in a large territory that needs to connect with regional systems of protected areas where other actors are part of the decision-making process* (C_09). These responses largely conform to the narrative noted earlier: more science, and better ability to use it, were

Table 2

Knowledge governance in Colombian Protected Areas. Columns in italics present extracts from the interviews; *follows Mc Nie et al. (2015). Acronyms: SINA: National Environmental System; IDEAM: Institute of Hydrology, Meteorology and Environmental Studies; IGAC: Geographic Institute Agustín Codazzi; CGR: Coffee Growing Region study site; WWF: Word Wide Fund Colombia.

CIVIC EPISTEMOLOGY			
CENTRAL LEVEL		REGIONAL / LOCAL	
Formal scientific narrative Scientific and expert knowledge recognised and valued Robust accountability provided by scientific and technical knowledge at central level. Tendency to pragmatism and demonstrate results through studies, but vary according to audience High level institutional arrangements (SINA) provide objectivity Formal rules provide guidance for accountability and transparency	*We need information systems for making diagnoses and to justify management* (C_01) *Water provision is helping to support our budgetary needs [to the government]. When we disclose this information we demonstrate to the different sectors and government how protected areas contribute and can be taken into account in the policies and strategies* (C_02) *Many decisions are made using information that comes to us officially, for example land use and coverage, comes from the IDEAM or the IGAC, other information comes from the research institutes* (C_07)	Management is diverse in practice, and incorporate diverse epistemologies and ontologies to negotiate agendas Regional and local management more accountable to local knowledge CGR: protected areas has been critical for territorial planning allowing inter institutional cooperation to incorporate climate variables for water management, heterogeneous expert bodies, and iteration with different stakeholders Amazon: different disciplines, including local knowledge are combined for management and decision making	*There are very interesting exercises with participation from many institutions and social groups to take part on the decision making of the watershed, all these actors are part of an agenda and of some concrete actions* (L_02) *Climate change brings more challenges, we need to address the issue across all strategic lines in order to influence local and national planning instruments (L_07)*
KNOWLEDGE SYSTEMS			
CENTRAL		REGIONAL / LOCAL	
Expert knowledge from academy, institutions or individuals with long history of collaboration with PNN Scientists as information providers Legitimacy mainly through evidence based decisions	*We use information from national organisations as IDEAM, but also from projects with international cooperation organisations and NGOs as WWF* (C_04)	Participatory processes to incorporate local knowledge (biodiversity) in planning CGR: strong collaborative arrangements at local level supporting experiential management Amazon: local knowledge, gaining relevance as reliable sources	*In the Otún basin the decisions are agreed with all the stakeholders, people do not allow for others to impose decisions, people participate, and ask the others to explain them better* (L_04) *Our perception about climate and biodiversity is different from what local communities perceive about the biological cycles (L_11)*
INTERVENTIONS			
CENTRAL		REGIONAL / LOCAL	
Boundary organizational management limited (SINA) due barriers in communication and knowledge exchange between parts, therefore scientific questions and management problems not negotiated between knowledge producers and decision makers Uncertainty*: Tendency to reduce uncertainty using information with the highest level of detail	*We need to strengthen the national environmental information system, to consolidates knowledge, not just a repository of information, this is fundamental for planning and management of the areas (C_09)* *Our premise is to use scientific information to have rigorous information; the academy or the SINA institutes produce this type of rigorous information and that is well accepted by decision makers (C_06)*	Knowledge brokers facilitating the process to validate climate local knowledge and facilitate the analysis of climate information Amazon: Customary decision making conflicting with protected areas official rules (i.e. management plan vs. indigenous tribes life plan) Participatory processes to incorporate local knowledge (biodiversity) in planning	*Information from local communities is interesting, we need to compare it with the information produced by the SINA institutes and NGO's to support decision making (L_10)* *The relationship with indigenous communities is a challenge [we want] to get closer to their perspective, considering their worldview for a better management of the protected area (L_14)* *If a weather station is not synchronized with the official standards the IDEAM will not endorse it (Local_05)*

seen as the main solutions to the present day challenge of how to integrate climate adaptation into conservation objectives and plans.

3.2. At the local level

As noted earlier, PNN operates under a hierarchical planning structure, where governance arrangements are established centrally, and then relayed to local levels for implementation. This suggests that ideas and approaches evident at the central level might be replicated in a local context. The local narrative, however, was somewhat different. As indicated in Table 2, decision-making at the local scale tended to be more participatory and collaborative, with local stakeholders actively included. In the CGR study site, well established collaborative networks had their own governance arrangements, with shared decision-making and feedback processes (quote L_04 in Table 2). Knowledge brokers within the region are helping to navigate the formal and informal knowledge systems, including validating local climate observations and knowledge. While understandings between park staff and local communities may differ on climate change and biodiversity, it was widely agreed that their perspectives needed to be included. In the Amazon, collaborative governance arrangements were less well-established, but this consideration and desire to be inclusive extended to indigenous knowledges, despite very different worldviews.

These accounts indicate a flatter structure at the local level, where park managers understood their management task to be focused on maintaining relationships with key stakeholders in their area. This accountability to local stakeholders did not exclude scientific and technical knowledge. Data generated at the local level was also regarded as important. However, there are still multiple challenges to fully incorporate climate information in decisions that involve collaboration with other stakeholders at local and national level, and connecting monitoring information with operational aspects of management: *information from monitoring [water resources] is useful, but how can we incorporate this with local planning instruments and from there define concerted actions with other institutions?* (L_08). In other words, the usefulness of the data again was not only in guiding technical decisions, but in navigating the local governance of natural resource management. The value of scientific and technical knowledge in this navigation was not as clear in the local context.

3.3. Integration between Central and local levels?

Interventions and knowledge management responses at the local level have the potential to provide feedback to management instruments at higher levels, enabling communication between scientific and non-scientific communities. For example, water monitoring in relation to climate variability at Tayrona National Park helped to connect climate information with national-level decision making to better manage tourism in protected areas, demonstrating that science can also “feed up” from the local level: *water monitoring in Tayrona National Park has been important to talk about carrying capacity and ecotourism to connect local to the territorial and national levels* (C_03). There is also increasing interest at the central level in using local traditional knowledge to cover the gaps in scientific information: *in the Amazon they have monitoring data of certain species made with indigenous communities, and that is valid for us* (C_04). Ironically, it was the lack of meteorological stations that led staff to start using traditional indigenous knowledge for management. Integrating local knowledge may facilitate negotiation of the management of shared territories and there is growing interest in using it in decision making: *we need to capitalize on the knowledge from local communities that have another vision of their territories. Both types of information [scientific and traditional] are used and are valuable, management requires a combination of both* (C_07). However, they also emphasized challenges that come with incorporating traditional knowledge into planning, calling for mechanisms to validate it: *the information [local knowledge] is not systematized and it is not easy to understand the schemes that people use to talk about the weather* (C_10). In the CGR a different context of collaboration exists in the form of a regional protected areas system (Nadachowski Chávarro and Valencia Valencia, 2009) where strong relationships exist among diverse stakeholders (private sector, environmental authorities, researchers and local communities) allow managers to use, integrate and socialize different sources of knowledge. It also enables cooperation for decision-making and management of environmental services (e.g. water and tourism): *some results like the water [management] in the protected area, have been very positive and has been very participative and concerted with the communities* (L_03). This means that despite the interest in using other forms of knowledge, science is still considered the primary mechanism to support management. This was reinforced by claims that management under climate change requires improved monitoring and risk analyses for decision making.

3.4. The subtle interaction between knowledge and future adaptation processes

In the broader context, the SINA and the SINAP (Section 1.2) are the main institutional arrangements shaping boundary work between science and policy in Colombian protected areas. These mechanisms allow the interaction and collaboration of different actors at multiple levels, being an entry point for the exchange of diverse types of knowledge for adaptation. PNN as part of the SINA and a coordinating agency for the SINAP, has different tools to allow participation of stakeholders at different scales (Diaz Leguizamon, 2016). Our data supports this, and demonstrates how PNN is developing proactive knowledge-based processes while improving communication with external actors. This approach can facilitate the co-production of research questions, bringing scientific knowledge into management and the design of environmental monitoring. Participants explained that collaborative work is supporting initiatives such as early warning systems, a climate committee, new conservation schemes and territorial planning.

Participants still perceive that co-production of knowledge for long term decision-making needs to be improved: *sometimes it is not possible to connect and include all the variables for an investigation that can support decision-making, that’s why it is important to consider different disciplines* (L_04). Some suggested creating spaces for co-operating on evidence based decision-making, participatory research and use of climate information as a way to allow visibility of the information needs for management: [*we need to*] *establish a channel of communication between those producing information in the country, creating observatories of protected areas, climate change and variability for decision making, to have clear routes to know if the information has restrictions or if we can work in collaboration* (C_06). These collaboration spaces can challenge current power relations and provide legitimacy of diverse knowledge systems.

3.5. Addressing management challenges for future-oriented conservation

Climate change is perceived as a theme that can potentially connect strategic objectives and play a critical role in joint development of knowledge at the three levels: *Climate change connects our work, and in terms of the management plan, we are proposing that we need to identify the planning route and timeframes for climate change to be more evident in strategic planning and management* (L_14, see also quote L_07 in Table 2). However, participants had contradictory perceptions about the value of using climate information for future planning: some mentioned they needed more information to make decisions, for others the problem is not about the amount of information available but its adequacy at different temporal and spatial scales. Some recognized that information needs will change over time and, critical to enable adaptive planning and future strategic thinking, and also emphasized the need for more clarity on the management question and the purpose of climate information for decision making: *to align the information and the process of decision-making they [decision makers] need to know what they want* *beforehand, have clear questions* (C_11). These contrasting perceptions indicate the need to understand how climate change, as a cross-cutting issue, can be used in planning and can confront existing arrangements: *we get lost in the strategic issues, we need to find how the technicians have the strategic ability to connect climate change with our four institutional strategic lines and emergent topics of management and translate this for decision makers* (C_04). PNN has tools for short, medium and long term planning: risk analyses for operational decisions (early warning systems for short term management), the annual operations plan and management plan (five years), and an effectiveness management tool with timeframes of 1, 3 and 5 years. However, there is little clarity over timeframes and how to integrate the analysis of climate variability into these tools: *short term are those decisions made in a week or maximum one month, medium term are those decisions taken between 3–6 months or a year.* (C_10), and: *our medium-term planning is the National Development Plan [5 years], our planning is closely related to the objectives of this National Development Plan"* (C_01). Also: *[for] effectiveness of the management the tool is run three times: 1, 3 and 5 years, [but] I think that the tool lacks one [long term] cycle, I would do it every 1, 5 and 10 years* (C_08). PNN acknowledge that these current tools can be adapted to specific contexts in each protected area (Diaz Leguizamon, 2016). Although this still relies on formal rules, it might open a door to change existing arrangements in the future.

Our data reflects the dominant narrative of science as the main form of knowledge at Central level, but results from the pilot sites show that managers are open to use other forms of knowledge to address uncertainty in management (Table 2). In the CGR although they attempt to reduce uncertainty by using information with the highest level of technical detail, collaboration arrangements with other actors (including local communities, academy, private sector) is helping to integrate diverse forms of knowledge in decision making. On the other hand, managers in the Amazon Piedmont site do not regard climate uncertainty as an obstacle for management, and there are ongoing exercises to incorporate local knowledge that relate climate variability with ecological transformation (quote L_11 in Table 2). These management responses to deal with climate change at local levels can demonstrate alternative models that meet some of the needs of the broader system. We see how climate change can motivate actors to change the existing institutional arrangements and boundaries, allowing a conversation between diverse stakeholders to better integrate information and start changing current management.

3.6. *Learning to enable effective knowledge exchange and management*

Participants' perception of barriers to effective knowledge management for climate adaptation included external limitations (i.e. those not dependent on individual capabilities), such as funding restrictions and access to equipment: *[climate change] is more about technical capacity, people here are very well prepared, but it is more about instruments and technology; with more resources we could be able to acquire those devices and train people to collect the information* (C_08). There are also cultural barriers related to individual capabilities, motivation, or attitudes towards new technology: *some people from parks have not been able to learn to use the new technologies, or they just prefer to work as always [using handwritten reports]* (C_08). Participants mentioned that decisions in local protected areas are made day-to-day, encouraging responding rather than planning, and how some park rangers do not make decisions until they have compiled all available information: *some wait until they have all the results from studies, then they don't finish the management plan until they have everything and [planning] gets delayed* (C_07). Learning is seen as a complex process associated with formal training, while for individuals it relates to self-reflection for personal development, curiosity and imagination to overcome the tasks ahead. At an institutional level, participants from PNN perceived that learning is hindered by high staff turnover, but also cultural, technological and operational barriers such as lack of spaces to share information, urgent issues preventing self-reflection or documenting lessons learned. Interviewees acknowledged many opportunities for dialogue with colleagues, but discussions of how a decision was made are rarely properly documented. This prevent tracking how ecological transformation is integrated into decision-making.

Participants recognize that collaboration at local level is improving. For example, the regional systems of protected areas and different collaboration schemes demonstrate the potential to improve territorial planning and learning platforms for long-term conservation while connecting across levels of management. Interviewees acknowledge multiple efforts to learn about climate change, to collect information to support management, and that management needs to be more flexible. This includes incorporating new information into strategic planning, while accepting climate change as a pressure that transcends the time frame of management plans and protected areas boundaries: *[we need] a clear theoretical approach to recognize climate as a pressure beyond 5 years…the importance of connectivity for climate change adaptation at regional level, and at the national level [understand] the role of protected areas in the different national planning instruments* (C_10). PNN is making efforts to build a shared understanding around how climate affects management, including use of common language to share information across management levels, monitoring platforms and with external stakeholders. In this sense, learning is seen as strategic for future management of protected areas; not only collecting more information on climate impacts, but by acquiring knowledge from a variety of sources to understand ecological transformation and facilitate decision making: *we have learned with all those exercises that we need more practical things, not only to know if the glacier is going to disappear in 5 or 40 years, climate change has to be transversal from local to national scales, and how it is related to other risk factors such as land use change* (C_04). This learning has helped to empower PNN to negotiate agendas with other sectors, donors and collaborators: *climate change must be transversal from local to national level, and [we want to see] how it relates with other threats such as deforestation. We have more and more elements to do our work and now we can tell the donors that we are not just going to work for their goals but for the construction of national parks guidelines* (C_04). This approach has the potential to strengthen the boundary work between science/policy makers/communities for effective management and adaptation of protected areas in Colombia.

4. Discussion

Our data shows that the link between science and decision makers at the planning and policy level is complex, unevenly understood and lacks a clear narrative of what works, what is needed and the role of scientific climate information. Management of protected areas under climate change has been regarded as a matter of scientific and technical information by the conservation community, for example using vulnerability analysis of ecological attributes under different climate scenarios (Rowland et al., 2016; Wyborn et al., 2016). In the case of Colombia, scientific knowledge from biodiversity inventories and ecological monitoring has been the basis of the decision-making system (Hurtado-Guerra et al., 2013), and there is an extensive body of institutions involved in scientific knowledge processes for decision-making (Sierra et al., 2017:44).

Our data confirmed that managers prefer to rely on scientific information to support decisions. This reflects a civic epistemology where decision making gains credibility through objective, science based approaches, and experts provide knowledge that is considered credible (Beier et al., 2016; Fernández, 2016). The hope is that science will inform policies to protect environmental values for society. However, we found specific and different contexts accross scales and between study sites relating to different users, roles, stakeholders and knowledge exchange systems. While participants generally considered that scientific knowledge is the best foundation for decision-making, our study sites had different arrangements to integrate and communicate a range of

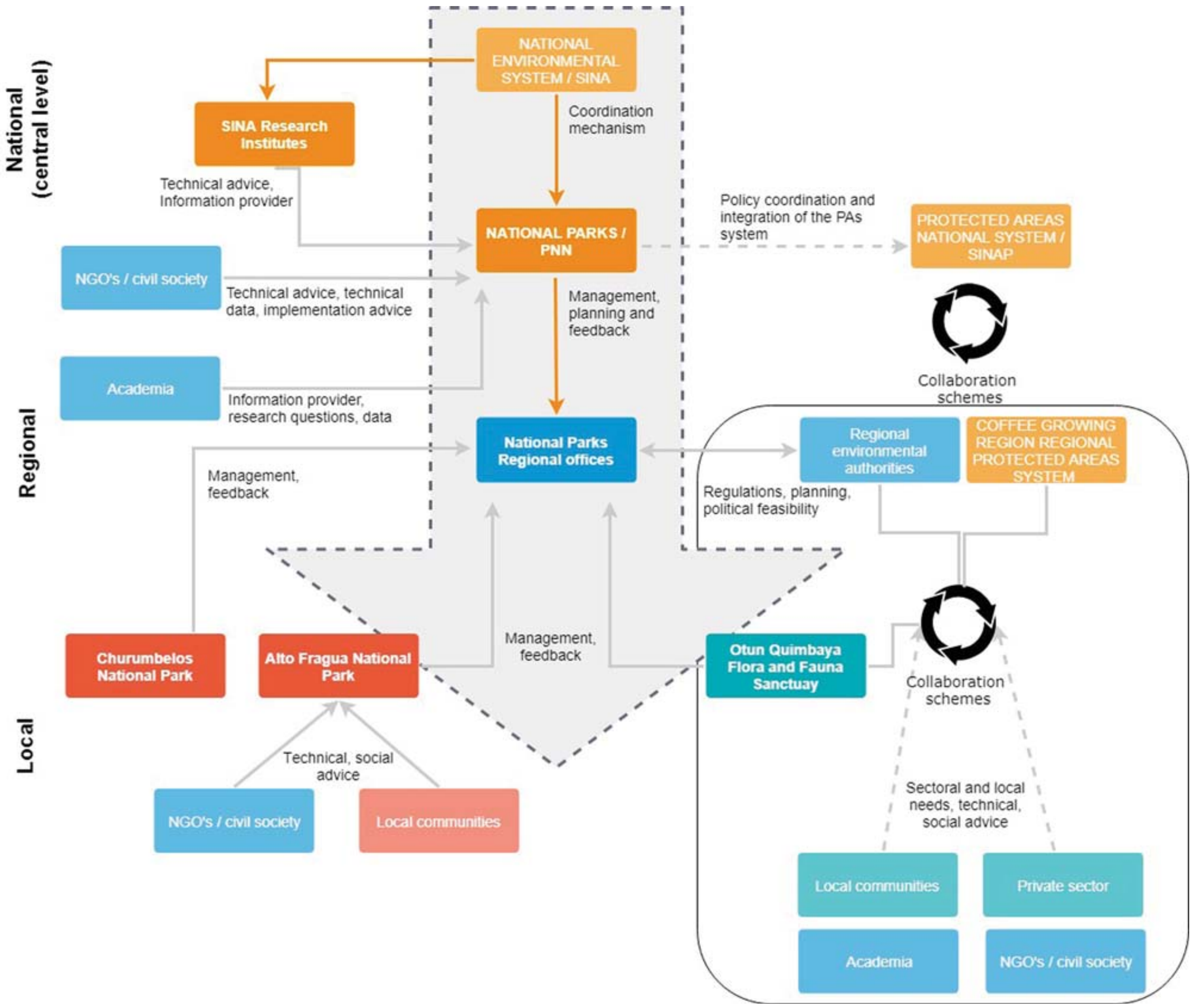

Fig. 2. Knowledge governance map for protected areas management in Colombia. The dotted arrow shows the hierarchical scientific narrative flowing from Central to regional and local management levels. In the CGR case study (bottom, right) knowledge management responses flows from local to higher levels of management enabling feedback and cross scale connection. In the Amazon Piedmont some barriers hinder feedback and information flows across levels.

knowledges. These differences draw on particular contexts, and to fully appreciate the complexity around protected areas management in Colombia it is important to understand the cultural and socioecological context that frame decisions around environmental systems in each site. In Colombia, environmental systems reflect the space where society and ecosystems have integrated themselves creating a range of differentiated images in people minds. Each system represents a complex physical and social structure with specific climatic, geographic, economic and cultural variables, providing a starting point to understand territorial management (Carrizosa Umaña, 2014).

The CGR has a long history of colonisation, complex socioeconomic development, and a particular cultural attachment between people and their region (Christie, 1978; Carrizosa Umaña, 2014), where territorial development emerged around coffee farming. This allowed the development of some of the best agricultural infrastructure services in the country, which reflect the shared vision and interests of its inhabitants. In the CGR, current strategies of collaborative planning have proven effective for strategic management of water resources and sustainability of aquatic ecosystems (Section 3.2 above; Buitrago Aguirre et al. (2014)). These rules supported a knowledge system based on inter-institutional cooperation and the incorporation of climate variables into planning (SEI, 2015) within a broader context of negotiation with production and conservation goals. For the CGR, protected areas have been critical for planning and participation of diverse stakeholders in management (Nadachowski Chávarro and Valencia Valencia, 2009). The Amazon Piedmont is the ancestral territory of different indigenous groups that have their own vision to manage the territory. Colonization from non-indigenous groups is more recent and has roots partly in the internal conflict in the country and also by oil extraction that has been an important driver for the local economy (Carrizosa Umaña, 2014). In this context, although managers expressed a preference for scientific information to guide decision-making, practical limitations led them to draw on indigenous knowledge, creating a new collaboration and appreciation for diverse knowledge sources.

In PNN, barriers for using climate information for management under climate change include technical and institutional constraints and a mismatch between information needs and availability of climate information (Jones et al., 2016). The dominant narrative prioritizing technical information, especially at Central level, reflect a resistance to change and explains why quality of information is often perceived as a barrier for making decisions, as mentioned by participants, and reported by Vásquez-Uribe and Matallana-Tobón (2016). Similar constraints have been reported from Australia Cvitanovic et al. (2016) and specifically in relation of climate information and long-term policy making by Jones et al. (2016). The institutional, financial and individual capacities needed to facilitate knowledge exchange between science and managers demands a culture that values management of information and knowledge (Cvitanovic et al., 2016). We argue that integrating climate change in long term management goes beyond the availability of scientific information and is related to deep-seated structures and processes of how societies value and use information (e.g. quote C_01 and C_07 in Table 2). Aligning societal values with current and emerging knowledge systems that integrate scientific information with expertise held by practitioners, local and indigenous communities and other stakeholders can re-orientate knowledge management interventions, and results from the case studies demonstrate that it is possible to have more integrative and diverse management. For example, conceptualizing the knowledge challenge as "more effective provision of scientific information to local level managers" – the dominant narrative of the prevailing civic epistemology – invokes top-down, centrally-driven strategies (Fig. 1). Focusing only on scientific knowledge neglects cultural and historical aspects of human cognition, and that people are "knowledgeable agents" who interact in complex political contexts where common knowledge is created (Jasanoff, 2005).

Despite strong emphasis on technical knowledge, our data indicates that practice is more diverse and subtle. Reframing the knowledge challenge as "supporting interactions between the actors in the knowledge system" encourages a flat structure that enables dialogue between practitioners and information providers, as demonstrated by our case study sites. However, it is important to understand this in the specific environmental systems and contexts that are enabling these changes locally. The differences between institutional structures and interventions are reconciled in the knowledge management responses (e.g. C_03 Section 3.1). At local level diverse knowledge systems are opening the door to incorporate other forms of knowledge for managing protected areas (Fig. 2). Alongside collecting, analyzing and communicating climatic information, a more effective approach involves collective agreement on management questions (e.g. C_11 Section 3.5) to facilitate sharing knowledge to solve practical problems (McDermott and O'Dell, 2001); developing a shared understanding of what is known about management objectives; understanding the impacts of climate variability and extremes (e.g. C_05, Section 3.1); and how science can inform policy (Parker et al., 2017). Our results in the CGR validate that multi-stakeholder coproduction of knowledge is possible and effective for climate adaptation (e.g. L_03 Section 3.3).

In Colombia's protected areas, close collaboration of practitioner agencies (WWFC), boundary organisations (SINA) and policy makers (PNN) has helped elicit the needs and experience from each group, and connect science with policy making. Co-production of knowledge between actors in the management of social ecological systems is critical to strategic planning: understanding barriers or enablers of how actors exchange information and address their differences is a basis for effective knowledge management arrangements (Kleinsmann and Valkenburg, 2008; Reyers et al., 2015). In Colombian protected areas, the current context of collaboration and the existing boundary organizations demonstrate the existence of coproductive capacities to reach effective environmental governance (van Kerkhoff and Lebel, 2015v). Based on our results, and following Gustafsson and Lidskog (2018) analyses on boundary organizations, we suggest that including diverse forms of knowledge can provide an opportunity to reshape elements of the current boundary organizations and enable a transition in the current dominant epistemology towards a more dynamic system. This requires acknowledging the existence of different forms of knowledge that represents multiple realities, that can provide new elements and pathways for future planning and climate change adaptation (Klenk et al., 2017). In the case of Colombian protected areas, despite the interest of using other forms of knowledge for management, it is important also to recognize local knowledge not just as fragmented data (Klenk et al., 2017) and avoid the temptation to "validate" it to fit into conventional models. Instead managers can learn to embrace the complexity of these diverse forms of knowledge as opportunity for adaptive management (Tengö et al., 2014).

Finally, we want to acknowledge some challenges in implementing collaborative research like this. It demands time and resources to build the relationships that enable fieldwork and support data analysis. Also, overcoming the barriers identified here requires creating capacities at individual, institutional and financial levels as suggested by Cvitanovic et al. (2016). We benefitted from a genuine interest from our partners in better understanding knowledge-based processes and their management, which opened conversations and consideration of how to use information more effectively. Our interview results were provided as feedback throughout the FPC project, and reinforced with our participants the interventions needed to transform existing institutional arrangements to deal with climate change. Identifying a mismatch between what they deemed desirable (more and better science) and how knowledge system actually operated (sharing knowledge across sectors and scales) helped managers to see opportunities in linking diverse knowledge systems to societal values and benefits from protected areas. In brief, this reinforced how strategic thinking for management of protected areas under climate change requires access to a range of scientific and non-scientific information from different sources, to enable collective learning, deliberation and reflection. This is critical to transform current knowledge systems towards relevant and effective adaptation.

5. Conclusion

Knowledge governance structures for natural resource management in Colombia have traditionally focused on meeting territorial planning interests to guarantee water supply for agriculture and economic development (Rojas Lenis, 2014), or conservation of migratory and native species (Quintero-Toro, 2012). This focus has evolved towards a participative, multi-institutional process, with a SINA (the knowledge institutions) that supports PNN in its role of preserving national protected areas. As proposed by Jasanoff (2005), the State (PNN and SINA institutions) provides scientific evidence to society of the need to protect environmental benefits. Using the knowledge governance framework allowed us to understand existing narratives framing decisions around future planning, current thinking and practices for management of protected areas, and to challenge those narratives. It also requires understanding the institutional arrangements that prevent or enable change (van Kerkhoff et al., 2018v). This can enable governance transformations needed to overcome barriers to use climate information (Jones et al., 2016) and include other forms of knowledge.

For Colombian protected areas, civic epistemology reflected a dominant scientific narrative for decision making, an approach that obscures the needs and practices of local communities and other stakeholders. The case studies demonstrated that in practice, the knowledge systems are rich, proactive and diverse, providing opportunities to integrate and validate other forms of knowledge. PNN and WWFC are identifying and working with government, civil society, academia and the private sector to coordinate planning and adaptation across sectoral and administrative boundaries. Maintaining creative relationships to address barriers to change, while including diverse world views, is central to enable decision making in these complex systems (Cumming et al., 2015; Fernández, 2016). The challenge of improving knowledge governance is to ensure that knowledge management interventions support networks and institutional arrangements that enable multiple flows of knowledge. Simply adapting current planning to incorporate climate information will not guarantee information is used in decision making, or that feedback for management of protected areas occurs across scales. More efforts are required so that all relevant stakeholders understand current science-policy boundaries and agree on how to renegotiate managerial authority, collaboratively define agendas to reconcile scientific and non-scientific communities taking advantage of diverse forms of knowledge in the system. Finally, we reinforce the importance of future research and implementation to understand cultural narratives, contexts, capabilities, networks and knowledge-sharing in specific decision making contexts. Such research will support building shared understandings about ecological transformation and climate change and provide clarity on the research and management approaches for the proactive management of protected areas under uncertain climate futures.

Acknowledgements

The authors would like to acknowledge financial support provided by the Luc Hoffmann Institute. CM was supported by a Luc Hoffmann Fellowship grant (project number P10002150, PO#2174). We thank the interview participants from PNN, WWF, CARDER and Universidad Tecnológica de Pereira for their time and sharing valuable information; P. Echeverry, O. Guevara (WWF Colombia) and C. Figueroa (Luc Hoffmann Institute) for organizing interviews; T. Trang (Australian National University) for support with Nvivo; M. Colloff (ANU), C. Wyborn (Luc Hoffmann Institute) and the anonymous reviewer for constructive reviews of the manuscript. Special thanks go to all the PNN staff who collaborated with us during the Future-proofing Conservation project.

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