Conservation Biology

Contributed Paper

Knowledge co-production and boundary work to promote implementation of conservation plans

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Abstract: *Knowledge co-production and boundary work offer planners a new frame for critically designing a social process that fosters collaborative implementation of resulting plans. Knowledge co-production involves stakeholders from diverse knowledge systems working iteratively toward common vision and action. Boundary work is a means of creating permeable knowledge boundaries that satisfy the needs of multiple social groups while guarding the functional integrity of contributing knowledge systems. Resulting products are boundary objects of mutual interest that maintain coherence across all knowledge boundaries. We examined how knowledge co-production and boundary work can bridge the gap between planning and implementation and promote cross-sectoral cooperation. We applied these concepts to well-established stages in regional conservation planning within a national scale conservation planning project aimed at identifying areas for conserving rivers and wetlands of South Africa and developing an institutional environment for promoting their conservation. Knowledge co-production occurred iteratively over 4 years in interactive stakeholder workshops that included co-development of national freshwater conservation goals and spatial data on freshwater biodiversity and local conservation feasibility; translation of goals into quantitative inputs that were used in Marxan to select draft priority conservation areas; review of draft priority areas; and packaging of resulting map products into an atlas and implementation manual to promote application of the priority area maps in 37 different decision-making contexts. Knowledge co-production stimulated dialogue and negotiation and built capacity for multi-scale implementation beyond the project. The resulting maps and information integrated diverse knowledge types of over 450 stakeholders and represented >1000 years of collective experience. The maps provided a consistent national source of information on priority conservation areas for rivers and wetlands and have been applied in 25 of the 37 use contexts since their launch just over 3 years ago. When framed as a knowledge co-production process supported by boundary work, regional conservation plans can be developed into valuable boundary objects that offer a tangible tool for multi-agency cooperation around conservation. Our work provides practical guidance for promoting uptake of conservation science and contributes to an evidence base on how conservation efforts can be improved.*

Keywords: bridging organization, FEPA, freshwater conservation planning, integrated water resource management, knowledge exchange, participatory mapping

La Coproducción de Conocimiento y el Trabajo de Frontera para Promover la Implementación de los Planes de Conservación

Resumen: *La coproducción de conocimiento y el trabajo de frontera le ofrecen a los planeadores un marco nuevo para diseñar críticamente un proceso social que fomente la implementación de los planes resultantes en*

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Paper submitted March 18, 2015; revised manuscript accepted May 28, 2015.

DOI: 10.1111/cobi.12560

colaboración. La coproducción de conocimiento involucra a accionistas de diversos sistemas de conocimiento trabajando repetidamente hacia una visión y acción común. El trabajo de frontera es un medio de creación de fronteras permeables de conocimiento que satisfacen las necesidades de múltiples grupos sociales mientras mantienen la integridad funcional de los sistemas de conocimiento contribuyentes. Los productos resultantes son objetos fronterizos de interés mutuo que mantienen la coherencia a lo largo de todas las fronteras del conocimiento. Examinamos cómo la coproducción de conocimiento y el trabajo de frontera pueden resolver el vacío entre la planeación y la implementación y promover la cooperación entre sectores. Aplicamos estos conceptos a las fases bien establecidas de la planeación de la conservación regional dentro de un proyecto de planeación de la conservación a escala nacional enfocado a la identificación de áreas para la conservación de ríos y humedales de Sudáfrica y al desarrollo de un ambiente institucional para promover su conservación. La coproducción de conocimiento apareció repetidamente a lo largo de cuatro años en talleres interactivos de trabajo para los accionistas, que incluyeron el co-desarrollo de objetivos de conservación del agua dulce nacional e información espacial sobre la biodiversidad de agua dulce y la viabilidad de la conservación local; la traducción de las metas a aportes cuantitativos que se usaron en Marxan para seleccionar áreas de conservación de proyectos prioritarios; la revisión de áreas de proyectos prioritarios; y el empaquetamiento de los productos cartográficos resultantes para promover la aplicación del mapa de área prioritaria resultante en 37 contextos de toma de decisiones. La coproducción de conocimiento estimuló el diálogo y la negociación y construyó la capacidad para la implementación multiescala más allá del proyecto. Los mapas resultantes y la información integraron diferentes tipos de conocimiento de más de 450 accionistas y representaron >1000 años de experiencia colectiva. Los mapas proporcionaron una consistente fuente nacional de información sobre las áreas prioritarias de conservación de ríos y humedales y se han aplicado en 25 contextos de uso desde su creación. Cuando se enmarcan como un proceso de coproducción de conocimiento respaldado por el trabajo de frontera, los planes de conservación regional pueden transformarse en objetos valiosos que ofrecen una herramienta tangible para la cooperación multiagencia en la conservación. Nuestro trabajo proporciona una guía práctica para promover la comprensión de la ciencia de la conservación y contribuye a una base de evidencias de cómo se puede mejorar la conservación.

Palabras Clave: FEPA, intercambio de conocimiento, manejo integrado de recursos hídricos, mapeo participativo, organización conectiva, planeación de la conservación de agua dulce

Introduction

Conservation planning is applied to promote the representation and persistence of biodiversity in a way that makes efficient use of limited conservation resources (Margules & Pressey 2000). Early efforts focused on developing systematic methods, biodiversity data, and spatial tools for identifying areas of high biodiversity value within a region (Sarkar et al. 2006). Slow uptake of the resulting plans prompted the incorporation of several social and institutional dimensions into regional conservation planning approaches (Cowling et al. 2003; Knight et al. 2006; Pressey & Bottrill 2009).These approaches reflected a concerted effort to improve understanding of the political, social, economic, and institutional complexities of moving from knowledge to implementation.

The social sciences offer a rich body of theory and frameworks for guiding such approaches, some of which are beginning to infuse the conservation planning literature, such as transdisciplinary research practice (Reyers et al. 2010), adaptive management (Holness & Biggs 2011), social-ecological systems thinking (Ban et al. 2013), social network analysis (Mills et al. 2014), and social marketing (Wilhelm-Rechmann & Cowling 2013). Emerging wisdom highlights the importance of including diverse knowledge types (e.g., scientific and experiential) and paying careful attention to knowledge exchange processes (Fazey et al. 2013). Unlike the traditional view of knowledge being produced by researchers and then transferred to users, this requires a more interactive, multi-dimensional mode of iterative knowledge co-production in a participatory arena that puts researchers, decision makers, and other users of knowledge on equal footing (Young et al. 2014). Such knowledge co-production inevitably requires effective boundary work for bridging the boundaries between groups of people with differing views of what constitutes reliable or useful knowledge (Rose 2015).

We examined how knowledge co-production and boundary work in conservation planning can bridge the gap between planning and implementation and promote cross-sectoral cooperation. We applied these concepts to well-established regional conservation planning stages (Pressey & Bottrill 2009) within a conservation planning project that had the dual aims of identifying areas for conserving rivers and wetlands for all of South Africa and developing a supportive institutional environment for promoting river and wetland conservation. The project was called the National Freshwater Ecosystem Priority Areas project (NFEPA), and the areas identified for conservation were called freshwater ecosystem priority areas (FEPAs). We considered the concepts of knowledge co-production and boundary work and the scientific and institutional context within which NFEPA was conceived. We developed the NFEPA approach by incorporating knowledge co-production and boundary work into existing conservation planning stages, and then evaluated the early evidence of uptake of the resulting conservation plans into policy and management. Finally, we reflected on the utility of this approach for conservation planners interested in producing policy-relevant science that translates into implementation. It is our intention that this paper, together with the unfolding conservation outcomes in the next decade, serve as a case study for researching ways of improving the links between planning and implementation.

Knowledge Co-Production and Boundary Work

Knowledge co-production is defined as "the collaborative process of bringing a plurality of knowledge sources and types together to address a defined problem and build an integrated or systems-oriented understanding of that problem" (Armitage et al. 2011). Evidence suggests that when people are closely involved in knowledge production, they are more likely to view the resulting knowledge as credible, salient, and legitimate and to adopt such knowledge for implementation (Cash et al. 2003). Credibility refers to the scientific robustness of the arguments and outputs, salience deals with relevance to user needs, and legitimacy represents the extent to which the information is perceived as fair, unbiased, and respectful of all stakeholders.

The process of knowledge co-production encompasses working iteratively and interactively toward collaborative learning, shared understanding of key concepts, and coevolution of common purpose and action. The work is transdisciplinary in nature and facilitates the exchange and co-production of knowledge not only between scientific disciplines (multi- and interdisciplinary research) but also between science and stakeholders from a variety of non-scientific knowledge domains (transdisciplinary research) (Young et al. 2014). Such an engaged approach helps uncover complementarities and create synergies across diverse knowledge systems. This generates an enriched picture of an issue of concern, which serves as a legitimate starting point for multiple stakeholders to participate in producing further knowledge (Jasanoff 2004; Tengö et al. 2014).

Exchange of knowledge between diverse knowledge systems is challenging and often characterized by lack of mutual understanding and tensions that arise from differing views of what constitutes credible, salient, and legitimate knowledge (Cook et al. 2013). Boundary work has been suggested as a means of managing these tensions. Originally conceived to explain how scientists intentionally defended the boundaries between science and non-science (Gieryn 1983), boundary work is now also applied as a means of creating permeable knowledge boundaries that satisfy the needs of multiple social groups (Jasanoff 1990; Clark et al. 2011). The right permeability should allow meaningful communication across boundaries while guarding the functional integrity of contributing knowledge systems (Bijker et al. 2009). The growing scholarship on boundary work (Guston 2001; Van Kerkhoff & Lebel 2006; Mollinga 2010) suggests that such work will promote uptake of research through facilitating meaningful participation of relevant stakeholders in issues framing and knowledge co-production.

Boundary work is commonly mediated by boundary spanners (Cash et al. 2003), boundary organizations (Parker & Crona 2012), or bridging organizations (Hahn et al. 2006). These individuals, teams, or organizations are perceived as neutral and are trusted by the relevant parties (Berkes 2009). They are skilled at mobilizing resources required for collaboration on issues of common interest, creating arenas for inter-organizational learning, trust building, and conflict resolution (Hahn et al. 2006).

A key aspect of boundary work is the creation and use of boundary objects, which establish a shared understanding of knowledge for action across multiple knowledge domains. Boundary objects are defined as co-produced outputs that are adaptable to different viewpoints yet robust enough to maintain identity across them (Star & Griesemer 1989). Examples of boundary objects include definitions and standards (Clark et al. 2011), models that integrate scientific and political viewpoints (White et al. 2010), and indicators that improve communication between different knowledge domains (Turnhout et al. 2007). Boundary objects allow local understanding and interests of participating groups to be reframed in the context of some wider collective activity, which can promote cooperation among stakeholders. This is particularly relevant in the context of conservation planning, where we propose that resulting maps have the potential to serve as powerful boundary objects for coordinating decision-making processes between multiple stakeholder groups and spatial scales.

Project Background

The NFEPA project benefited directly from some 6 years of piloting freshwater approaches to conservation planning in South Africa, during which time considerable progress was made in developing technical methods, collecting data, and building institutional readiness (Roux & Nel 2013). From a technical perspective, planning approaches for freshwater ecosystems advanced rapidly in the 2000s (Nel et al. 2009; Linke et al. 2011). In South Africa, these planning approaches lead to the collation of much national scale data that was used as the foundational data for NFEPA (Nel et al. 2009). Further work was done to improve data gaps and limitations (notably around wetlands).

Parallel to these technical advances, work for improving cooperation around conserving freshwater biodiversity in South Africa led to heightened institutional readiness among several government departments (Roux & Nel 2013). An institutional assessment revealed important challenges for freshwater biodiversity conservation,

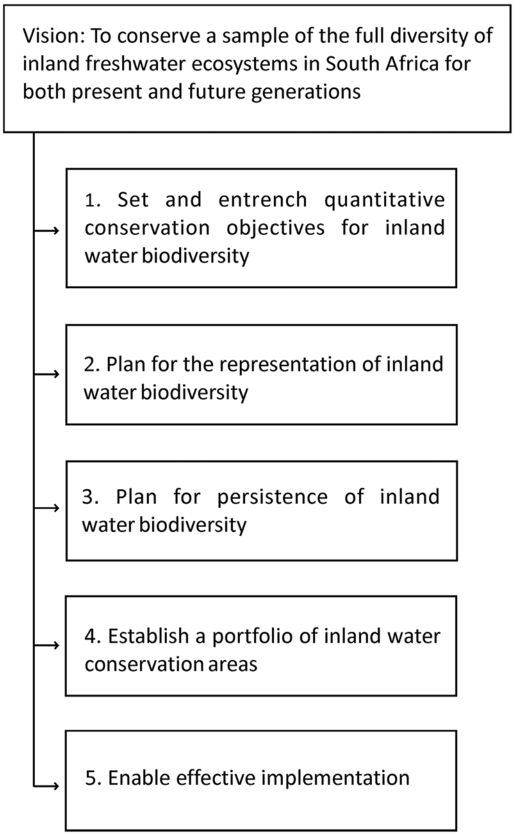

Figure 1. National vision linked to 5 policy objectives aimed at conservation of freshwater ecosystems in South Africa (after Roux et al. 2008).

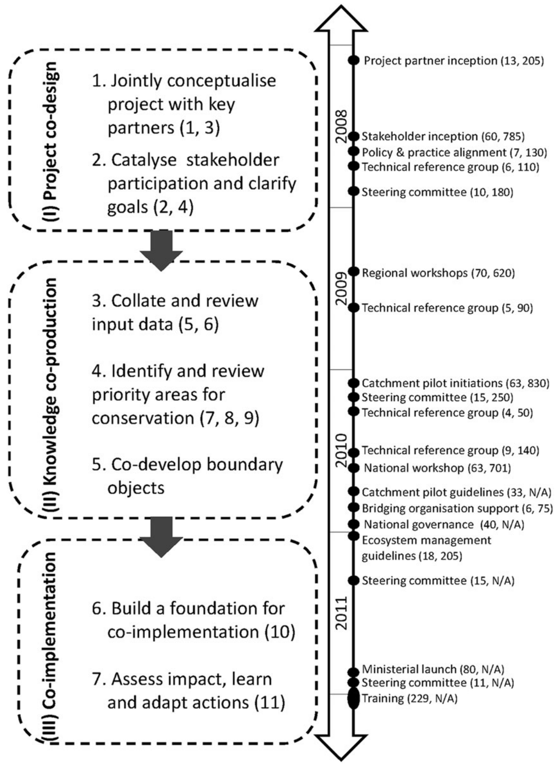

Figure 2. Framework used to guide the conservation planning and knowledge co-production approach used in the NFEPA project. Knowledge exchange occurred iteratively in phases I-III. Seven common conservation planning stages are shown on the left. Numbers in parentheses are stage numbers in Pressey and Bottrill (2009). The timeline shows the main stakeholder meetings that are explained in more detail in Supporting Information. Supporting Information includes an additional list of smaller stakeholder meetings. Numbers in parentheses along the timeline respectively indicate the number of participating stakeholders and the collective years of experience represented at the meeting.

including the lack of dialogue and cooperation across sectors and between levels of governance (national, provincial, catchment, and local) and the incompatibility of databases and decision-making tools used by regulating authorities (Roux et al. 2008). To address these challenges, key national government departments participated in a cross-sector policy process to develop shared policy objectives for conserving freshwater biodiversity (Roux et al. 2008). The resulting hierarchical policy framework linked a national vision for freshwater biodiversity conservation to a set of five cross-sector policy objectives that broadly encapsulated the principles of conservation planning (Fig. 1).

Methods

The NFEPA project served as an initial step toward enacting the cross-sector policy objectives (Fig. 1). From the outset, the aim of developing a national conservation plan (objectives 1–4 of Fig. 1) was strongly coupled to an aim of promoting an enabling institutional environment for achieving conservation outcomes (objective 5 of Fig. 1). The NFEPA approach used well-established stages of conservation planning (Pressey & Bottrill 2009) but added novelty through its explicit focus on 3 knowledge exchange phases (Fig. 2): project co-design, knowledge co-production, and co-implementation.

Project Co-Design

The NFEPA project was conceived and co-designed by scientists, practitioners, and research funders from eight key agencies involved in managing or conserving freshwater ecosystems (Supporting Information). These agencies had already jointly framed the key issues around conserving freshwater biodiversity and had developed a shared national vision and policy objectives (Fig. 1). The project team included scientists and practitioners from a range of disciplines, including aquatic and conservation sciences, geographic information systems (GIS), political science, and integrated water resource management. A formal project governance structure was set up to represent key participating agencies (Supporting Information). This included a steering committee of senior scientists and officials and a technical reference group of experienced conservation planners. These groups met at regular project milestones to iteratively review methods and results (Fig. 2).

Stakeholders were identified through snowball sampling (Biernacki & Waldorf 1981). Partner agencies nominated initial stakeholders in their respective domains and then these participants identified other relevant stakeholders. Stakeholder participation was designed to avoid stakeholder fatigue or overload in 2 ways. First, it allowed the stakeholders to link to their relevant level of technical detail by offering a range of participation opportunities with differing levels of involvement, such as newsletters, interviews, small group meetings, and review workshops (Supporting Information). Second, judicious and selective use was made of stakeholder time, with much technical work accomplished by the authors behind the scenes, but allowing some time for meaningful participation through iterative workshops designed to review results from previous stages and refine methods for forthcoming stages.

In the stakeholder inception workshop (Fig. 2), stakeholders were classified according to their desired level and type of participation. Thereafter, in a series of successive stakeholder workshops data were reviewed and collated, and dialogue and co-learning among stakeholders was catalyzed (Fig. 2). Three catchment-scale pilot projects were conducted to solicit feedback from users on early drafts of outputs to shape the final outputs, explore the implications of using the outputs at catchment and provincial scale, and build capacity for their use. The relevant years of experience of stakeholders who participated in map production was recorded over the course of the project.

Knowledge Co-Production

The shared national vision and policy objectives (Fig. 1) were used to co-develop stakeholder goals for guiding the selection of priority areas. These goals sought to represent a range of biodiversity features (including ecosystem types, species, and ecological processes) and promote conservation feasibility of priority areas.

The stakeholder goals were used to identify GIS layers needed for selecting priority areas (Supporting Information) (Nel et al. 2011*a*). The GIS layers were reviewed by local experts in three-day workshops held in five different regions around the country. Local experts were regarded as aquatic field ecologists, water resource planners, or catchment managers with many years of local knowledge. The workshops were designed to convert the tacit knowledge of local experts into explicit knowledge that could be incorporated into the GIS data. Participants systematically assessed the GIS data in every sub-catchment within their region and used collective judgment to refine existing data or add new data where necessary.

Stakeholder goals were translated into quantitative input data for Marxan (Ball & Possingham 2000) and used with the reviewed GIS layers to select draft priority areas (Nel et al. 2011*a*). The draft priority areas were reviewed at a two-day national workshop, which brought together senior officials who were working on water, environmental, and agricultural issues, as well as local experts from each of the five regions.

The workshop was designed to solicit joint negotiation and collective recommendations across all sectors and levels of governance. Plenary sessions addressed overarching issues, such as ideas for final map products and potential policy mechanisms for implementation. Break-away groups provided an opportunity for region-specific negotiation about the relative merits of each draft priority area and feasibility for its conservation. This negotiation process also considered how changes to draft priority areas would affect the achievement of representation requirements and resulting stakeholder goals. Decisions on changes to draft priorities were negotiated as a group, recommendations were captured on annotated hard copy maps, and review notes were linked to sub-catchment identifiers. These recommendations were used by the technical project team to finalize the priority areas.

The final priority areas were translated into maps of freshwater ecosystem priority areas (FEPA maps) for each of the 19 catchment-level administrative units in South Africa. The technical reference group met prior to the national workshop (Fig. 2) to propose draft map categories. These were guided by a hierarchical protection strategy for freshwater ecosystems that assigns 3 levels of protection, which embed high protection areas into 2 multiple-use zones with diminishing levels of protection (Abell et al. 2007). This protection hierarchy allows for human use while limiting impacts from upstream catchments and surrounding landscapes.

The proposed map categories were reviewed during the plenary session of the national workshop. Thereafter, they were finalized through a series of iterative workshops in 3 pilot-project catchments. Workshop participants identified key implementation mechanisms and developed proposed ecosystem management guidelines for each map category. The resulting guidelines were further reviewed in a workshop on ecosystem management guidelines (Fig. 2) that included aquatic ecologists and national, provincial, and catchment-scale practitioners. Implementation guidelines on how to use FEPA maps were developed for the key implementation mechanisms identified during several meetings with groups of experienced practioners (Supporting Information).

Co-Implementation

The catchment-scale pilot projects were conducted to build practical understanding and capacity for using FEPA maps at finer scales. Participants tested the application of the FEPA maps in their respective decision-making contexts and met iteratively over the course of several months (Supporting Information) to discuss and resolve application challenges. Catchment management strategies, in terms of South Africa's National Water Act (no. 36 of 1998), were under development in 2 of the pilots (Inkomati and Breed-Overberg). Several smaller meetings were held in these two catchments to devise recommendations that could feed into their catchment management strategies.

The South African National Biodiversity Institute (SANBI), a project partner, was formalized as a bridging organization to support ongoing use of FEPA maps and to steer the co-produced knowledge toward conservation outcomes. The institute had already played a key facilitating role during the project and was considered by stakeholders well-placed to negotiate the boundaries between science, policy, and implementation, as well as between national and provincial conservation agendas. The institute also agreed to provide free online access to the FEPA maps, the original data used to create the maps, and the documentation supporting the use of the maps from their Biodiversity GIS website (http://bgis.sanbi.org).

Political endorsement was sought through the launching of a FEPA atlas by the ministry of water affairs. At the launch, executive officials from each of the eight partner organizations (Supporting Information) signed a copy of the atlas as a symbol of institutional support for using FEPA maps. Following the launch, full-day training on how to use FEPA maps in different policy contexts was provided in four cities (Fig. 2).

We used the co-developed list of implementation mechanisms to assess the diversity of use since launching the FEPA maps. Information was collated from email requests sent to the project leader and project manager. Additional information was collected from practitioners in national, provincial, and catchment agencies at two annual Freshwater Ecosystem Network meetings. This network was created by SANBI after completion of NFEPA to advance the conservation of freshwater biodiversity in South Africa. We also quantified the number of visits to the NFEPA webpage on the Biodiversity GIS website.

Results

Over 450 stakeholders were engaged in the co-production and use of the FEPA maps over the course of the project (Fig. 2; Supporting Information). The majority of stakeholders were drawn from the water and environment sectors at national, provincial, and catchment levels of governance; a smaller proportion were drawn from the agriculture sector. Local stakeholders were mainly researchers and private consultants. The co-production of the FEPA maps (stages 1–5 of Fig. 2) involved over 200 participating stakeholders and represented more than 1000 years of collective experience (Fig. 2). Over 200 people were formally trained in regional training workshops.

The full suite of FEPA maps were packaged into an atlas (Nel et al. 2011*b*), which included hardcopy FEPA maps, a lookup table for the biodiversity within priority areas, and a DVD containing the underpinning data and a GIS viewer (ESRI 2010). Figure 3 is an example of a FEPA map and shows the different map categories. The maps showed that approximately 25% of South Africa's river length and 38% of its wetland area will require a high level of protection to conserve representative examples of freshwater biodiversity (protection level 1) (Table 1). A further 9% of river length and 24% of wetland area contain specific fish species requirements and other ecological processes (protection level 2) (Table 1). The ecosystem management guidelines included 207 recommendations for managing key land use activities in different FEPA map categories (Fig. 4). These were packaged into an implementation manual (Driver et al. 2011), along with guidelines for using FEPA maps within 37 key implementation mechanisms that were identified in the pilot catchment workshops (Supporting Information).

Just over 3 years since launching the atlas, FEPA maps have been used in at least 25 of the 37 use contexts listed in the implementation manual (Table 2; Supporting information). The protection of FEPAs has been formalized into a national water resource strategy that guides the implementation of the National Water Act (DWA 2013) and formalized in 2 catchment management strategies of the NFEPA pilot catchments (BOCMA 2010; Inkomati 2013). Integrated water resource planning processes currently underway at catchment scale have led to numerous FEPAs being proposed for the highest level of protection in terms of the National Water Act (in many cases, some 80% of all FEPAs in the catchment). Once finalized, this process will give legal status to the protection of the FEPAs (Supporting Information). The FEPAs have also been formalized into bioregional planning policy (Government Gazette 2014) and used in a number of regulatory decision-making contexts, such as environmental impact assessments, strategic environmental assessments, and mining and prospecting applications (Supporting Information). The data underpinning the FEPA maps have been used in national assessments (Driver et al. 2012) and the development of local freshwater management plans (Roux & Nel 2013) (Table 2). At least two environmental non-governmental organizations use FEPA maps to inform the strategic goals of their freshwater

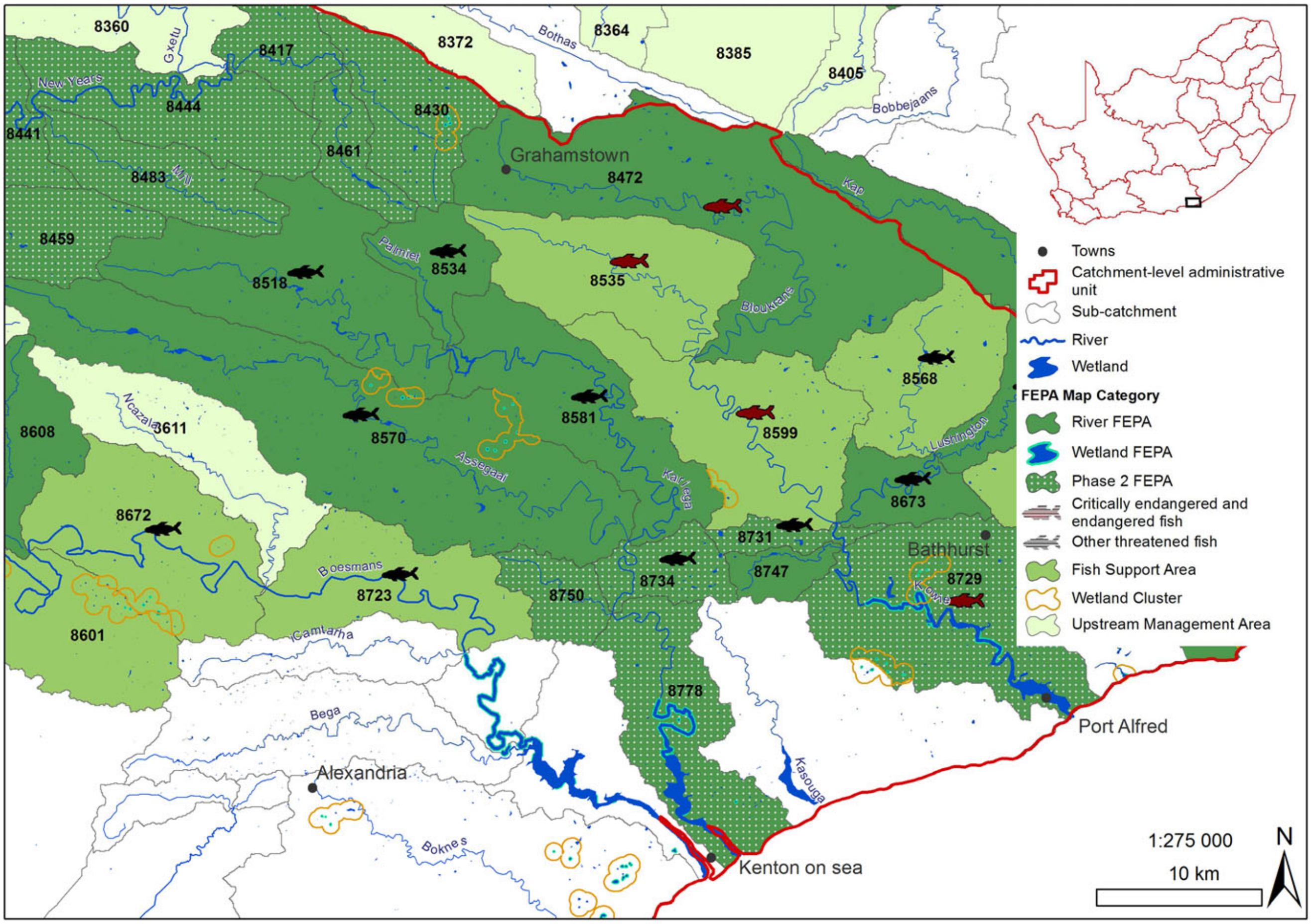

Figure 3. Example map showing freshwater ecosystem priority areas (i.e., a FEPA map) in South Africa. The map reflects knowledge systems of stakeholders from a range of different sectors and can be viewed as a boundary object that provides a tangible tool for multi-agency cooperation around conserving biodiversity.

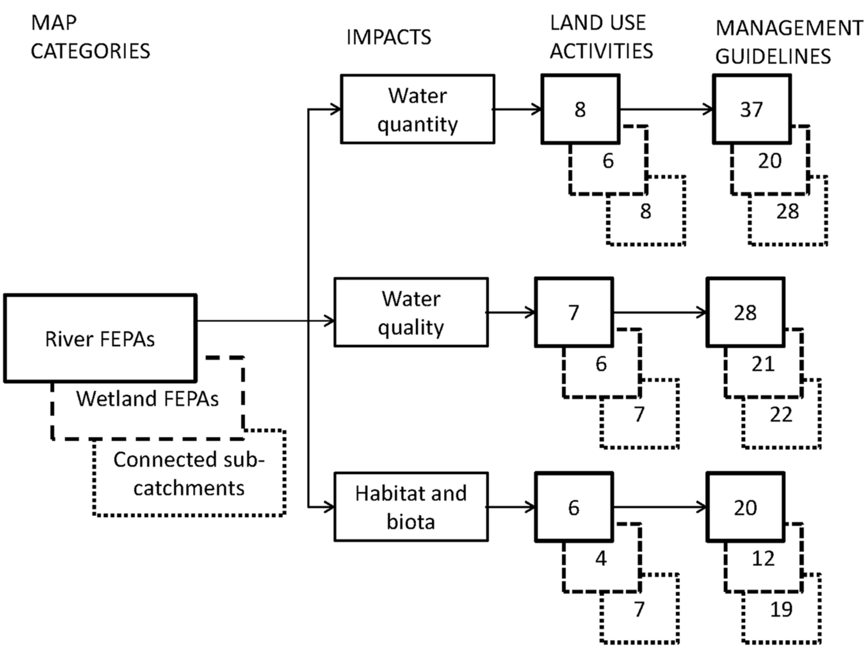

Figure 4. Structure of the co-developed ecosystem management guidelines. The guidelines target three categories on the maps of freshwater ecosystem priority areas ('FEPA maps'), each with distinguishable management requirements. For each map category, management guidelines are provided for the most common land use activities associated with adverse impacts on water quality, quantity, and habitat or biota. The number of land use activities and management guidelines specified for each map category are provided, rather than the actual activity or guideline. A full set of guidelines is provided in Driver et al. (2011).

Table 1. Stakeholder goals used for identifying priority areas, each with a rationale and the method used to translate them into quantitative input data for Marxan.

Stakeholder goal and rationale[a]	*Quantitative input for Marxan*[b]
(1) Represent diversity of river and wetland ecosystems as coarse-filter biodiversity surrogates that include the emergent properties of ecosystems as well as species (Higgins et al. 2005).	(1) Representation requirements are based on Roux et al. (2008): at least 20% of the total length of each *river ecosystem type* and 20% of the total area of each *wetland ecosystem type* in South Africa.
(2) Represent threatened freshwater species as fine-filter biodiversity surrogates (Higgins et al. 2005), where limited options remain for their conservation; included only indigenous freshwater fish species, acknowledging the need to include a broader range of taxa in future.	(2) Representation requirements are set to prevent further species becoming vulnerable (IUCN 2012): 100% of critically endangered or endangered populations; minimum of 10 populations (or maximum existing) for other *threatened or near-threatened populations*, preferably coinciding with critically endangered or endangered populations.
(3) Represent large free-flowing river reaches that flow undammed from source to sea, or to major confluence. This represents natural processes such as flow regimes, erosion and sediment transport (Pringle 2001).	(3) Representation requirements are based on Roux et al. (2008): at least 20% of the number of *free-flowing river* systems in each *river ecoregion* group.
(4) Represent wetland clusters, which are clusters of wetlands embedded in a relatively natural landscape matrix between which species dispersal processes can occur.	(4) Representation requirements are based on Roux et al. (2008): at least 20% of the total area of *wetland cluster* within each *wetland vegetation group*.
(5) Align selection of priority areas with protected areas, to enhance conservation feasibility.	(5) Planning unit cost is based on area of sub-catchment, reduced by the area of overlap with *protected areas*.
(6) Align selection of river priority areas with priority estuaries to promote the persistence of estuaries.	(6) A decaying discount was applied to the planning unit cost so that sub-catchments closer to a priority estuary were preferentially selected over ones further away or in catchments with no priority estuary.
(7) Select priority areas that take into account the connected nature of freshwater ecosystems, to limit impacts from upstream sub-catchments.	(7) A penalty was applied to the boundaries of upstream, non-headwater *sub-catchments* of selected planning units.
(8) Preferentially represent river ecosystem types that are in rivers of good ecological condition. Human use conflicts are generally lower in such rivers, thus conservation is generally more feasible. Such rivers are also more likely to promote persistence of biodiversity.	(8) Marxan's conservation feature file and planning unit versus conservation feature file were configured to achieve representation requirements in rivers of good *ecological condition* first, before proceeding to those in a moderately modified condition to achieve the remaining representation requirements.
(9) Preferentially select wetlands of known conservation importance by local experts, or ones with threatened species associations. Thereafter use a wetland condition index modeled from land cover data.	(9) Marxan's conservation feature file and planning unit versus conservation feature were configured to achieve representation requirements first in *wetland ranks* 1 and 2, before proceeding to ranks 3 and 4. Artificial wetlands and those in a highly transformed landscape were excluded.

[a] *Stakeholder goals aligned with a co-developed shared national vision (Fig. 1), which included aspirations for representing at least 20% of each major freshwater ecosystem type in South Africa (Roux et al. 2008).*
[b] *The GIS layers used to translate the goals to quantitative Marxan input data are in italics and described in more detail in Supporting Information. Further technical details are provided in Nel et al. (2011*a*).*

programs. The NFEPA GIS website was visited over 1.2 million times by 9989 unique visitors between October 2011 and January 2015.

Discussion

The science of conservation planning has traditionally been undertaken somewhat separately from the implementation phase (Ban et al. 2013). By framing the exercise as an intermeshed technical and social process from the outset, conservation planning offers a powerful tool for stimulating landscape-level systems thinking, integrating diverse knowledge systems, and translating knowledge to implementation. The NFEPA project achieved this by using well-established scientific methods of conservation planning embedded in a strongly participative institutional process. There are several generic insights to be gained from use of this approach to

Table 2. Description of categories on the FEPA maps in Fig. 3.

Protection level[a]	*Map category*	*Description*	*Extent (%)*[b]
1	river FEPAs	Achieve representation requirements for river ecosystem types, threatened or near-threatened fish species, and free-flowing rivers. FEPA status applies to the river reach shown within the sub-catchment (Fig. 3). River FEPAs are currently in a good ecological condition and need to remain this way.	22
1	wetland FEPAs	Achieve representation requirements for wetland ecosystem types. Wetland FEPAs that are currently in a good ecological condition should be managed to maintain this condition, and those that are not should be rehabilitated to the best attainable ecological condition.	38
1	phase 2 FEPAs	Identified in moderately modified rivers, only in cases where it was not possible to fully achieve representation requirements for river ecosystem types in rivers that were still in good ecological condition. These rivers may become rehabilitation priorities but only once river FEPAs are considered fully rehabilitated and well managed.	3
1	presence of a threatened or near-threatened fish species	Achieve representation requirements for threatened or near-threatened fish species. A red fish symbol indicates at least one population of a critically endangered or endangered fish species, whereas a black fish indicates the presence of vulnerable or near-threatened fish populations (Fig. 3). There should be no further deterioration in river ecological condition in fish sanctuaries and no new permits should be issued for stocking invasive alien fish in farm dams in the associated sub-catchment.	18[c]
2	fish support areas	Achieve representation requirements for threatened and near-threatened freshwater fish species (those with a fish symbol on Fig. 3), or depict important fish migration routes (those without a fish symbol). Those without a fish symbol differ from river FEPAs in that they are currently not in a good ecological condition, but need to be managed to support the associated fish populations.	9
2	wetland clusters	Achieve representation requirements for groups of wetlands embedded in a relatively natural landscape. Not all wetlands in a wetland cluster have to have FEPA status, but the connected landscape matrix should be managed to promote ecological processes such as species dispersal between wetlands.	24
3	upstream management areas	Catchments in which human activities need to be managed to prevent deterioration in the ecological condition of downstream river and wetland FEPAs and fish support areas.	32

[a] *Protection level 1 areas impose the highest level of protection; levels 2 and 3 provide diminishing levels of protection.*
[b] *Percentage of the total river length or wetland area.*
[c] *Representation requirements for fish were achieved either through the allocation of river FEPAs or fish support areas. This value is therefore also incorporated into river FEPAs or fish support areas.*

promote cooperative implementation of conservation plans.

Project Co-Design

The focus on project co-design helped ensure a representative and transdisciplinary team that included 12 project team members drawn from 8 partnering agencies, which represented different knowledge domains (Supporting Information). This is in line with Young et al. (2014), who recommend improving the science-policy dialogue by promoting interdisciplinarity on the science side and cross-sectoral integration on the policy side. The project was also framed as a partnership between funders, practitioners, and scientists on the basis that the needs and expectations of all three of these groups must be addressed adequately to diffuse new knowledge into the implementation domain (Roux et al. 2010). Core team members represented well-known national facilities associated with advances in conservation science (Supporting Information). The steering committee and technical reference group included senior officials representing funders, implementing agencies, and researchers (Supporting Information). The resulting broad partnership and representation provided a sense of accountability which was, at least in part, responsible for political

Table 3. Examples of different ways the maps of freshwater ecosystem priority areas (FEPA maps) have been used since their launch.

Proactive planning[a]
national water resource strategy (1)
catchment management strategies (2)
integrated water resources planning through classification of water resources (3)
bioregional planning (9)
biodiversity management plans for ecosystems (11)
municipal integrated development plans and spatial development frameworks (22, 23)
non-governmental organization strategies and programs (34)
management plans for protected areas (14)
public works restoration programs (31, 34)
Regulatory application[a]
alien and invasive species regulations (12)
environmental impact assessment and management frameworks (17, 18)
mining and offset guidelines (19, 25)
aquaculture permitting (27)
water use authorizations (6)
biodiversity stewardship (16)
National assessment using underpinning data[a]
river ecological condition (37)
national biodiversity assessment (Driver et al. 2012)

[a]*Numbers in parentheses cross-reference to Supporting Information on different uses of the maps of freshwater ecosystem priority areas (FEPA maps), which provides further detail on each use context and evidence of use.*

endorsement and widespread diffusion of the FEPA maps to policy and management levels (Table 2). The original intent of NFEPA was to guide national, provincial, and catchment level planning, but the review workshops around the country— in which the many local experts participated— catalyzed considerable interest in using the FEPA maps in regulatory mechanisms at local scale (Table 2). In hindsight, the project would have benefited from explicit representation of local government on the steering committee from the outset.

Knowledge Co-Production

The focus on knowledge co-production built the credibility, salience, and legitimacy of the FEPA maps. Evidence suggests that these are 3 essential elements required for translating knowledge to action (Cash et al. 2003). With almost 30 years of theory, frameworks, and tools behind it, conservation planning offered a credible scientific methodology for selecting FEPAs. The substantial experience and diverse stakeholder representation that went into co-producing the FEPA maps (Fig. 2) provided further credibility, as well as legitimacy. The co-development of implementation guidelines for different use contexts further promoted the salience of the FEPA maps. Capturing all three of these elements in the resulting FEPA maps led to the diversity of uses currently observed (Table 2).

Linking the shared national vision and policy objectives to stakeholder goals and, in turn, to quantitative Marxan input data was an effective means of actively engaging with stakeholder values and operationalizing technical aspects of conservation planning. It helped build trust in the technical process, which was reinforced through stakeholder review of the resulting draft priority areas. Although this approach is a recognized step in conservation planning (stage 4 in Pressey & Bottrill [2009]), in practice quantitative inputs into conservation planning software are seldom co-developed through an iterative process that meaningfully engages stakeholder values and goals.

The framing of FEPA maps as shared boundary objects made explicit their potential in many different use contexts (Table 2). It highlighted the need for generic map categories (Fig. 3) and supporting guidelines (Fig. 4) that could be understood and applied by stakeholders in different knowledge domains. Over a year of effort was therefore devoted to co-producing FEPA maps from the draft priority areas and exploring their use implications in pilot catchments. The resulting FEPA maps integrated diverse knowledge systems and have provided a systematic and consistent information source across the country that is used by many different sectors for making decisions that affect freshwater biodiversity (Table 2). The FEPA maps therefore offer flexibility in that they can be interpreted differently depending on the stakeholder employing them, yet are robust enough to coordinate conservation actions that work towards achieving a desired outcome. As such, they represent a powerful boundary object for linking communities and forging cooperation around the conservation of freshwater biodiversity. Although there are instances where conservation plans are developed for single agencies, most regional conservation plans require cooperative implementation to achieve their goals (Pressey et al. 2013). We believe developing maps as boundary objects has good potential for producing conservation plans that promote cooperation and that this should be considered as an explicit step in multi-agency conservation planning exercises (e.g., between stages 9 and 10 in Pressey & Bottrill [2009]).

Co-Implementation

Just over three years from launching, the FEPA maps and associated information have been applied in 25 of the 37 decision-making contexts originally identified (Supporting Information). This was undoubtedly supported by free access to the data via the online website, which has received over a million visits. As Ruckelshaus et al. (2013) reflects, the effectiveness of science ranges from developing new knowledge, re-defining how issues are framed and perceived, diversifying the options for implementation, and producing outcomes for ecosystems and people. It appears that NFEPA was effective across a range of these impact pathways. The project co-produced new knowledge (summarized in the FEPA maps and associated management guidelines) and diversified implementation options as it was mainstreamed into several polices, strategies, and projects (Table 2). Although difficult to measure, the acronym *FEPA* has also become part of the narrative of several communities of practice operating in the domains of water resource management, conservation planning, biodiversity assessment, and impact assessment (Driver et al. 2012; DWA 2013). The final conservation outcomes will need to be monitored, and conservation plans will need updating in line with the successes or failures (Pressey et al. 2013). Future work should critically evaluate the utility of the FEPA maps in achieving freshwater biodiversity outcomes, as well as the contribution that the concepts of knowledge co-production and boundary work made to the planning exercise.

Conclusion

The NFEPA project combined concepts from conservation planning, knowledge co-production, and boundary work to enhance the credibility, salience, and legitimacy of planning outputs. The project addressed important challenges for conserving freshwater biodiversity, by stimulating dialogue and cooperation among sectors and levels of governance and providing FEPA maps to serve as a compatible decision-making tool. Interactive knowledge co-production workshops and widespread training on the use of FEPA maps also helped build the capacity of implementing agencies for managing and conserving freshwater biodiversity. Three years after launching the FEPA maps, the science uptake has been very rewarding. We are optimistic that the uptake of FEPA maps will translate into real outcomes for the conservation of freshwater biodiversity and believe this work provides practical guidance for conservation planners interested in promoting uptake of their science and an evidence base for reflection and learning on how conservation efforts can be improved.

Acknowledgments

This work was supported by all NFEPA project partners: the Council for Scientific and Industrial Research, South African National Biodiversity Institute, Water Research Commission, Department of Environmental Affairs, Department of Water Affairs, Worldwide Fund for Nature, South African Institute for Aquatic Biodiversity, and South African National Parks.

Supporting Information

Further details on project partnering agencies and governance structure (Appendix S1), stakeholder participation (Appendix S2), GIS data used in the conservation planning exercise (Appendix S3), the different uses of the FEPA maps (Appendix S4), and the structure of the ecosystem management guidelines that accompanied the FEPA maps (Appendix S5) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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