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Integrated cross-realm planning: A decision-makers' perspective

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Abstract

Pursuing development and conservation goals often requires thinking and planning across terrestrial, freshwater and marine realms because many threats and social-ecological processes transcend realm boundaries. Consequently, effective conservation planning must consider the social and ecological links between realms and follow a cross-realm approach to allocate land/water uses and conservation actions to mitigate cross-realm threats and maintain cross-realm ecological processes. Cross-realm planning requires integrating multiple objectives for conservation and development, and assessing the potential co-benefits and trade-offs between them under alternative development scenarios. Despite progress in cross-realm planning theory, few fully-integrated and applied cross-realm plans exist. The gaps between research and implementation are not unique to cross-realm planning, but are accentuated by the complexity of spatial decision-making entailed. Based on a collaborative process including scientists, resource managers and policy-makers, we developed an operational framework for cross-realm planning based on up-to-date thinking in conservation science, but offering practical guidance to operationalise real-world planning. Our approach has a strong theoretical basis while addressing the visions and needs of decision-makers. We discuss the foundations and limitations of current approaches in cross-realm planning, describe key requirements to undertake this approach, and present a real-world application of our framework.

Keywords: integrated cross-realm planning; integrated land-sea conservation planning; cross-system threat; cross-system ecological process; multi-objective planning

1. Introduction

It is increasingly recognised that best-practice in systematic conservation planning, a key approach guiding conservation interventions worldwide (Kukkala and Moilanen 2013), requires consideration of the ecological and socioeconomic links between terrestrial, freshwater, and marine realms (Álvarez-Romero et al., 2011; Beger et al., 2010). One reason is to address threats originating in one realm and affecting others, which requires designing conservation areas and managing human activities to minimise cross-realm threats (Nel et al., 2009; Stoms et al., 2005). Another reason for considering connections between realms is the maintenance of ecological processes, such as cross-realm nutrient subsidies (Naiman et al., 2002), or the protection of habitat for species occupying multiple realms (Burger et al., 2000). Prioritising management for interconnected realms independently can lead to inadequate allocation of management actions or land/water uses if: (1) cross-realm threats are ignored and/or remain unmanaged, thus compromising the persistence of biodiversity or ecosystem services within the realm where planning is undertaken (Tallis et al., 2008); or (2) features of conservation and/or socioeconomic interest (hereafter 'assets') rely strongly on ecological connections between realms and require concurrent actions across realms (Álvarez-Romero et al., 2011; Hazlitt et al., 2010). Furthermore, managing one realm can affect ecosystems in linked realms (Rieman et al., 2010), which can result in co-benefits, if management achieves objectives in two or three realms more efficiently, or trade-offs, if management in one realm compromises the achievement of objectives in another (Adams et al., 2014a; Klein et al., 2012). In all cases, decision-makers are challenged with identifying and understanding the key links between realms and adjusting management actions to account for them (**Figure 1**).

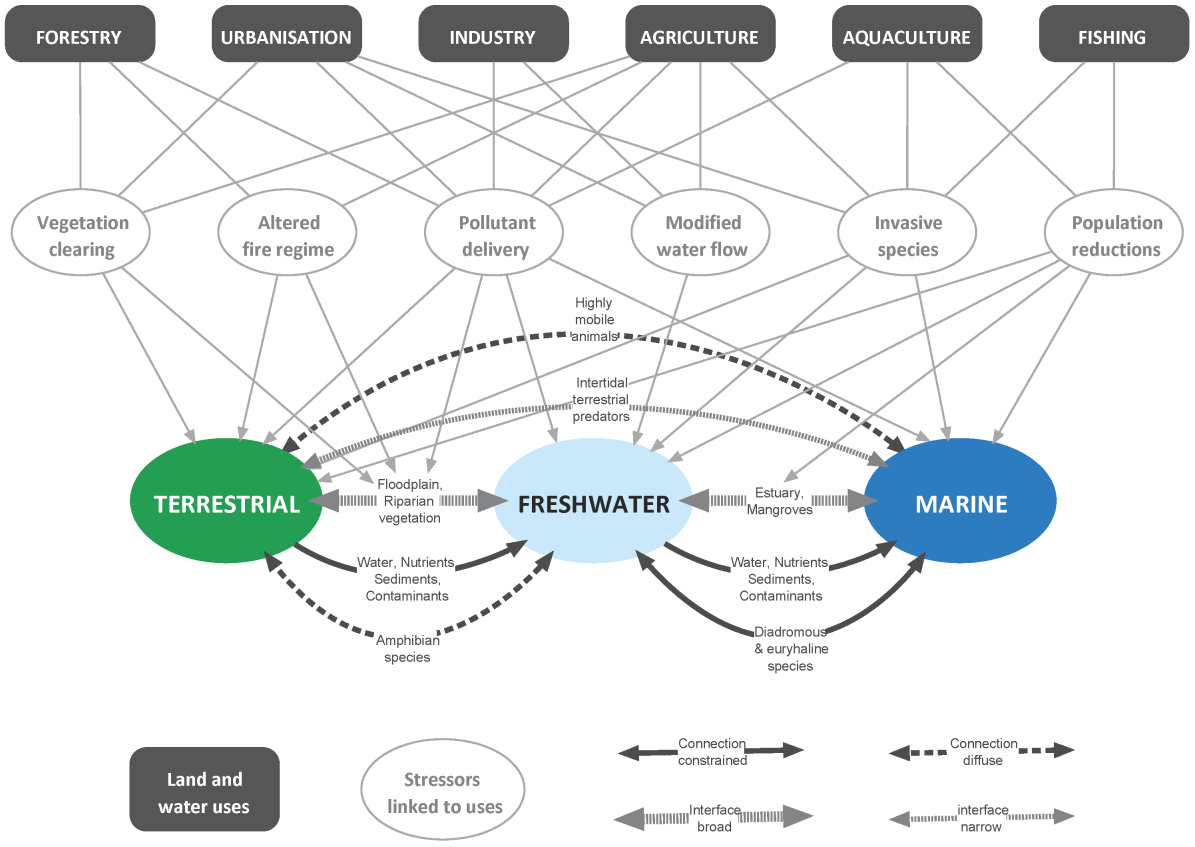

Figure 1. Links between terrestrial, freshwater, and marine realms identified by decision-makers. Grey arrows link uses and realms, and black/dark grey arrows depict threat propagation paths (e.g. constrained connections such as rivers). Decision-makers face complex social-ecological systems, in which management decisions (within and outside their jurisdictions) have consequences beyond their realms of interest. Cross-realm connections in any region will be numerous, but discussions with stakeholders can help to identify the most relevant and those for which there are spatial data. Examples of social-ecological links include vegetation clearing resulting in erosion and sedimentation in aquatic ecosystems, also affecting associated

fisheries, and coastal fisheries reducing marine subsidies to freshwater and terrestrial ecosystems sustained by anadromous fish migrations.

We define integrated cross-realm planning as a process to guide the spatial allocation of management actions and land/water uses to achieve explicit environmental and socioeconomic objectives across multiple realms. General goals of cross-realm planning include maintaining key ecological processes connecting realms, limiting cross-realm threats that compromise conservation or socioeconomic objectives, and balancing the benefits and trade-offs resulting from management decisions. The concept is founded on the general principles of systematic conservation planning, including complementarity between priority management areas and actions, cost-effective solutions to achieving objectives, and transparent and repeatable methods for prioritising management areas/actions or allocating uses (Kukkala and Moilanen 2013). Cross-realm planning also calls for integrating conservation prioritisations with established processes for water and land-use planning, traditionally undertaken independently (Pierce et al., 2005). Effectively, this means integrating multiple objectives (e.g. biodiversity, ecosystems services, agriculture) and assessing the potential co-benefits and trade-offs between them under alternative development scenarios (Moilanen et al., 2011); this in turn requires a multidisciplinary approach to planning and new decision-support frameworks to guide and facilitate this transition (Reyers et al., 2010). Our definition includes approaches with the same broad goals, including 'integrated land-sea conservation planning' (Álvarez-Romero et al., 2011), 'ridges-to-reef planning' (Lipsett-Moore et al., 2010) and 'catchment-to-coast planning' (Smith et al., 2011), but is wider in scope and aims to capture the full complexity of planning for multiple interconnected realms.

While natural resource managers and policy makers (hereafter 'decision-makers') are aware of the need, and are often required, to develop integrated plans (e.g. legal mandates, funding priorities, international best-practice guidelines), they often struggle to apply cutting-edge research approaches and tools for cross-realm planning (Álvarez-Romero et al., 2011). Factors constraining applied cross-realm planning include the relatively recent advances in methods to integrate planning across realms (Beger et al., 2010; Linke et al., 2012), lack of spatial data on cross-realm processes (Álvarez-Romero et al., 2011), uncertainty regarding the effects of management actions across realms (Adams et al., 2014a), difficulties in adjusting existing decision-support tools (Beger et al., 2010), and the complexities of coordinating diverse governance regimes (Kerr et al., 2014). Importantly, collaboration amongst organisations responsible for planning and implementing management actions in the different realms is generally poor. All these factors accentuate the gaps between research, planning, and implementation recognised for conservation planning (Knight et al., 2008). Therefore, given the array of barriers to cross-realm planning and the relative infancy of its application, there is a need for a framework to guide its operationalization in the real world.

Our primary aim is to enable applied cross-realm planning with a transdisciplinary approach, bringing together scientists and decision-makers, with a view to collaboratively producing an operational framework. We propose ways to achieve cross-realm planning with a strong theoretical basis while also addressing the needs of decision-makers, thereby helping to bridge the research-implementation gap. To achieve this goal, we do the following:

First, we outline current approaches in cross-realm planning, including a summary of progress in academic and practical applications, and use existing planning frameworks to identify major gaps;

Second, we describe our collaborative process with decision-makers, which aimed to understand the requirements of cross-realm planning, develop an operational framework that provides practical guidance, and highlight challenges in application; and

Third, we identify, based on advances in methods and tools, and a consideration of challenges, key research areas to further advance applied cross-realm planning, emphasising the value of collaborative processes.

2. Limitations of current approaches in cross-realm planning

Despite the recognised benefits of integrated planning, integration across realms has been only partly addressed (Adams et al., 2014a; Álvarez-Romero et al., 2011). Most planning exercises have focused on a single realm with some consideration for linked realms and most consider only links to one other realm, commonly terrestrial-marine or terrestrial-freshwater (**Figure 2**). Conservation planners have generally

focused on a single realm while addressing some cross-realm threats, but have rarely incorporated considerations for cross-realm ecological processes (Álvarez-Romero et al., 2011). Few studies have attempted to integrate priorities for management actions across realms, and these are mostly restricted to two realms, most often terrestrial-marine (e.g. Makino et al., 2013) or terrestrial-freshwater (e.g. Amis et al., 2009). Freshwater-marine exercises are rare and only partially integrated (e.g. targeting interface habitats: Beck and Odaya 2001). Planning with objectives for terrestrial, freshwater, and marine systems has been seldom attempted and is generally based on concurrent and/or sequential optimisation across all realms (e.g. Vander Schaaf et al., 2006). Other suggested approaches not yet implemented in cross-realm planning regard the upstream benefits of managing marine areas (e.g. restricting coastal fishing to maintain marine subsidies to upstream areas: Darimont et al., 2010) or promoting downstream benefits to marine ecosystems through improved freshwater management (Plagányi et al., 2014).

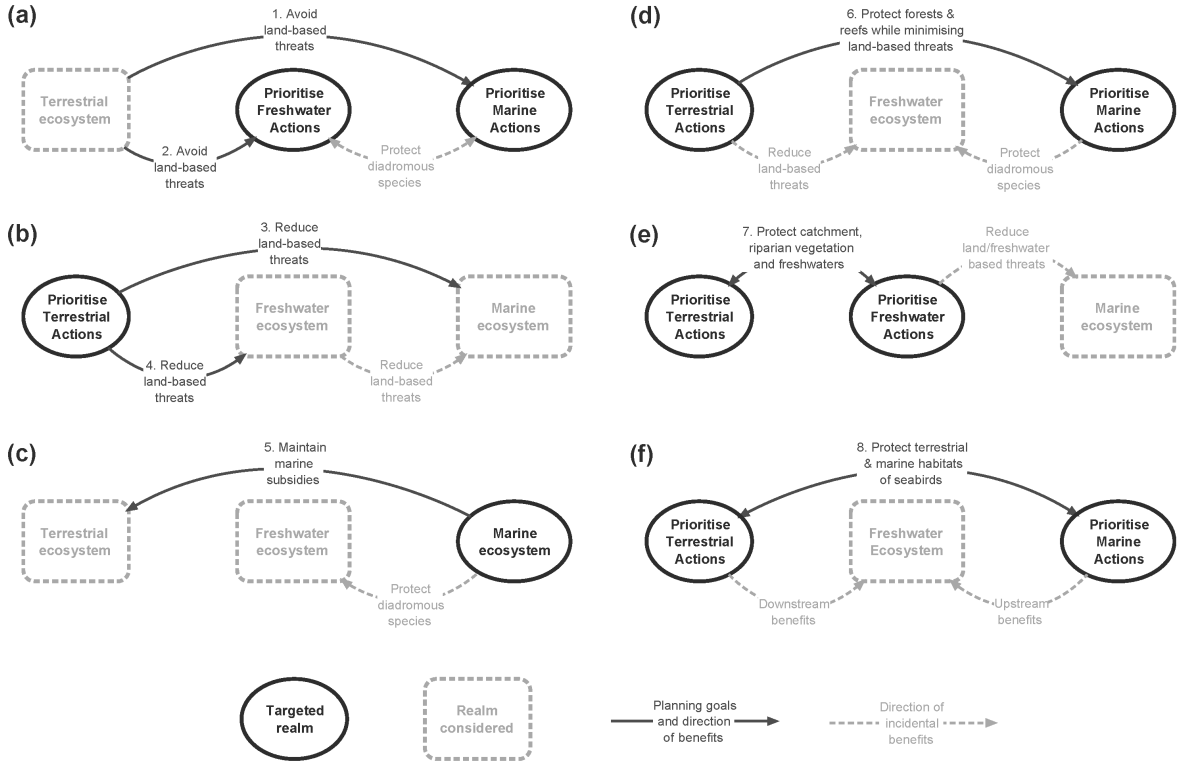

Figure 2. Integrated planning exercises commonly target a single realm, with some considerations for linked realms. Targeted realms contain the assets of principal management interest and/or indicate where actions should be implemented to achieve cross-realm objectives, which relate to linked (also considered) realms. **(a)** Typically, cross-realm plans seek to maximise the ecological integrity of conservation areas in marine (1: e.g. Tallis et al., 2008) or freshwater (2: e.g. Linke et al., 2007) realms by minimising exposure to land-based threats. **(b)** A related but different approach is to manage the sources of cross-realm threats to prevent or reduce the magnitude of their impacts. An example of this approach is prioritising catchment management to reduce terrestrial runoff and minimise impacts on marine (3: e.g. Álvarez-Romero et al., 2014; Klein et al., 2012) or freshwater (4: e.g. Linke et al., 2012) ecosystems. **(c)** Prioritising protection of marine areas that also contribute subsidies to terrestrial ecosystems exemplifies integration of cross-realm processes (5: e.g. Lombard et al., 2007). Integrated planning exercises allocating actions in multiple realms are less common and generally restricted to two realms, including **(d)** prioritising terrestrial and marine conservation areas while minimising land-based threats (6: e.g. Klein et al., 2010; Klein et al., 2014) or **(e)** simultaneously targeting terrestrial and freshwater assets (7: e.g. Amis et al., 2009; Noss et al., 2002). Another approach requiring concurrent management of multiple realms to maintain cross-realm processes is **(f)** prioritising terrestrial and marine actions to protect species with habitat requirements in both realms (8: e.g. Hazlitt et al., 2010).

A major gap in cross-realm planning is the lack of consideration of socioeconomic interactions between realms, for example the benefits and costs that management actions can have on different stakeholders (Álvarez-Romero et al., 2011). A contributing factor to this gap is that cross-realm planning tends to be led

by environment-focused organisations with little participation of development or production-oriented organisations (e.g. agriculture, fisheries, forestry). Consideration of socioeconomic aspects in cross-realm planning mainly comprises technical analyses of the cost-effectiveness of applying actions on one realm versus another to achieve ecological goals in a single realm (e.g. identifying land- and sea-based conservation actions to mitigate threats to coral reefs: Klein et al., 2010). These approaches can be extended to identify the socioeconomic and ecological co-benefits and/or trade-offs of applying different actions with cross-realm impacts (e.g. prioritising rehabilitation considering multiple ecological and economic objectives: Hermoso et al., 2012). Yet, identifying and explicitly setting socioeconomic objectives is still restricted to single-realm planning (Ban et al., 2013).

In summary, our examination of current cross-realm planning indicates that:

1. Decision-makers are aware of and have attempted cross-realm management, but have generally lacked a systematic approach to selecting areas for management;

2. Most systematic approaches are academic exercises generally not developed for or suited to inform management, mainly due to limitations of data and models, and absence of decision-makers;

3. Academic and applied exercises have generally focused on a single realm and included only some cross-realm considerations, typically land-based impacts on marine or freshwater ecosystems;

4. Socioeconomic interactions are poorly integrated into planning; this is reflected in the lack of explicit socioeconomic objectives, which should be defined considering cross-realm interactions; and

5. Exploration of co-benefits and trade-offs of actions across realms has been limited, mainly due to incomplete information on responses of different assets to cross-realm threats and actions.

3. Toward cross-realm planning in practice: developing a new operational framework

While there have been important advances in theoretical approaches to cross-realm planning (Adams et al., 2014a; Álvarez-Romero et al., 2011), practical advice on their application for decision-makers is generally lacking (but see Klein et al., 2014 for an example of cross-realm planning influencing on-ground actions). Importantly, existing conceptual and operational frameworks are generally developed in academic settings without the participation of decision-makers responsible for implementing plans. To address this limitation, we assembled a group of applied researchers and decision-makers to discuss the requirements and challenges of integrated cross-realm planning. Together, we developed a new operational framework based on current theory, but reflecting the structure and detail required to facilitate its accessibility, application, and potential for adaptation to different contexts.

Early engagement of stakeholders in environmental decision-making is critical to develop a sense of ownership of the process and outcomes of planning (Reed 2008), as well as to ensure outputs are relevant to their needs (Pierce et al., 2005). Our collaborative approach was strongly based on the knowledge of decision-makers about NRM planning, in contrast to the more typical science-led approach. Our group was intentionally diverse, comprising eighteen researchers and decision-makers with a wide skills-base relevant to catchment and natural resource management (NRM). Researchers had backgrounds in ecology, environmental governance and applied conservation planning in terrestrial, freshwater, and marine realms in countries including Australia, Fiji, Mexico, Papua New Guinea, Palau, Solomon Islands, and South Africa. Decision-makers included representatives of government agencies and NRM organisations working in catchments in northern Australia (Gilbert, Queensland; Daly, Northern Territory; Fitzroy, Western Australia) and several catchments draining into the Great Barrier Reef lagoon. Organisations participating in NRM planning are commonly organised by hydrological regions, thus focusing on the catchment-scale allowed us to think about and describe the "typical" settings in which planners are required to consider cross-realm issues. The diversity in background and expertise contributed to the value and potential transferability of our framework to different regions.

We used a semi-structured focus group process (described below) based on three one-week workshops and follow-up meetings over an 18-month period. The process consisted of facilitated whole-of-group and

subgroup discussions, where researchers prompted decision-makers to identify and describe the needs and processes underpinning real-world planning processes. Group discussions held during workshops were perceived by participants as critical to facilitating transdisciplinary collaboration, information exchange, and integration of ideas between managers and scientists. In the words of participating decision-makers, "*the process itself was highly successful in aligning a diverse set of managers from across northern Australia with the science team*", provided "*an excellent mix of expertise which stimulated thinking*" and was "*valuable to better understand the process involved in cross-realm planning*". The overall process consisted of three steps:

Step 1 – Identify key considerations and requirements for cross-realm planning: Based on current planning processes, four regional (catchment-based) sub-groups identified and described the elements that decision-makers should consider for cross-realm planning. The whole group then identified regional differences, and common challenges and requirements.

Step 2 – Develop an operational framework that reflects common requirements while accommodating regional context: The next step consisted of whole-of-group discussions to conceptualize and develop an operational framework grounded in the key considerations for cross-realm planning, which addressed the common planning requirements and constraints identified during the first step. The framework identifies the planning stages/tasks (hereafter components) where cross-realm considerations are necessary and describes how different components are linked to each other (e.g. through information flow) and influence choices, decisions and outputs along the planning process.

Step 3 – Revisit context and specific planning needs for each catchment: Regional sub-groups worked through the framework in the context of their catchments, and identified how steps had been considered in existing planning processes and the challenges to including them in future planning. Based on subgroups' findings we identified unclear, extraneous and/or missing steps, ensuring the framework was comprehensive and adequate for interpretation by decision-makers.

Our deliberations resulted in three key outputs (below): conceptualisation of key requirements and considerations for cross-realm planning; an operational framework incorporating the vision and needs of decision-makers; and major challenges and opportunities for advancing cross-realm planning. Overall, participants agreed that the framework can guide planning initiatives in northern Australian catchments, and can be transferred to other regions.

3.1. Key requirements and considerations in cross-realm planning

Central to achieving cross-realm planning is the need to consider multiple objectives associated with managing different realms, which can result in co-benefits or trade-offs when prioritising actions. Also critical is recognising that the governance context (defined by existing institutional, political, and socioeconomic decision systems) will influence management and decisions about uses of land and water across realms, and will dictate which types of funding and actions are feasible. It will therefore be necessary to understand the current or potential overlap, gaps and coordination between institutions with jurisdictions over realms and how these interactions can affect management decisions. Overall, when setting multiple objectives in cross-realm planning, we noted six key considerations that interact to shape outcomes (highlighted in dark grey in **Figure 3**).

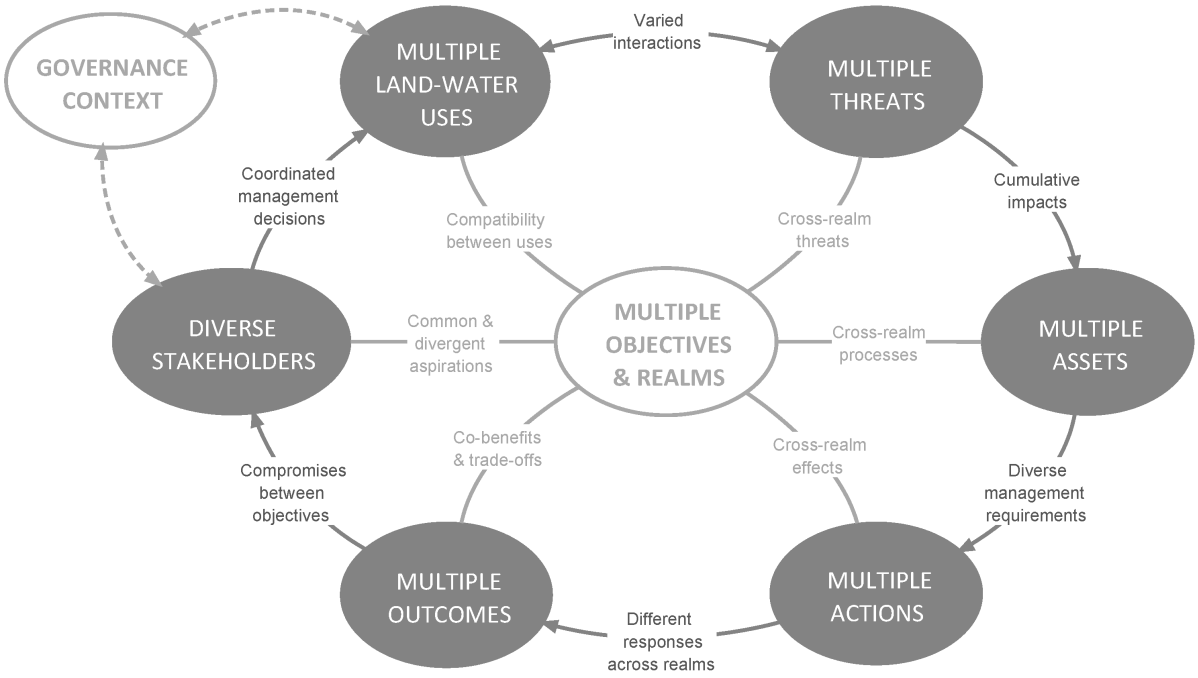

Figure 3. Conceptualization of the links between the six fundamental considerations in cross-realm planning emerging from the need to address multiple objectives across multiple realms

First, there are often diverse stakeholders who must be considered. Integrating stakeholders' preferences and aspirations into planning objectives will promote an equitable representation of their values in outcomes, and build trust in and ownership of the plan (e.g. Cowling et al., 2008; Lombard et al., 2010). Setting objectives is an inherently social process that requires exploring both scientific information as well as the subjective values of stakeholders as they relate to the environment (Chan et al., 2007; Wilhere 2008). However, once objectives are in place, designing a plan that meets these objectives, exploring trade-offs and co-benefits and designing monitoring requires quantitative data (both social and ecological) which can present a major challenge to cross-realm planning (Adams et al., 2014a). The process of eliciting objectives and then collecting relevant data to measure objectives can be costly in terms of financial resources and time required, particularly if stakeholders are spread over large geographic distances such as may be the case if planning at the catchment level, and should be accounted for when designing the planning process.

Associated with diverse stakeholders are multiple uses of land and water with varying levels of compatibility, which requires understanding the benefits and costs of potential uses across stakeholders (sometimes geographically distant, such as farmers and fishers). Consequently, decisions about resource management sometimes require coordination between stakeholders with interests or jurisdiction over different realms (e.g. Lombard et al., 2010; Pierce et al., 2005). Coordinated decisions will ensure the best use of resources and limited management budgets to achieve objectives, particularly when costs and benefits go beyond the realm of main interest.

Furthermore, when planning for resource management it is important to consider multiple threats to the social-ecological systems in the region. Threats can be associated with current uses of land and water, such as modified water flow or vegetation clearing, but can derive from past or distant uses (e.g. feral animals, modified fire regimes, altered water flows). Managing some threats, such as feral pigs, will benefit production and conservation across multiple realms through mitigating local (e.g. soil erosion) and downstream (e.g. poor water quality) management problems. There are likely to be varied interactions between threats and assets/uses of management interest. The potential interactions between threats (i.e. additive, synergistic or antagonistic) call for assessment of cumulative impacts, still in its infancy, as well as co-benefits or trade-offs between management actions to mitigate threats.

Multiple threats will influence multiple assets in various ways. Identifying the sources of threats and the assets they influence across realms therefore underpins decisions about where, when and how to act. Assets

of interest in a region include ecosystems and species with different conservation significance, but will also include, for example, areas with high suitability for agriculture or grazing and sites of cultural or recreational importance. As threats will affect assets in different ways and can propagate across realms, decision-makers will likely need to employ a diverse portfolio of management actions that will suit the management requirements of different assets and mitigate local and cross-realm threats cost-efficiently. Along with prescribed actions, decisions about land and water uses should reflect the desired balance between socioeconomic opportunities and management needs. An integrated plan thus needs to prioritise and coordinate the locations and types of actions and uses. Prioritisation of multiple actions and uses across space and time allows plans to meet objectives for multiple outcomes, which take into account the benefits and costs across diverse stakeholders and realms. Despite the compatibility of some land/water uses and potential co-benefits of actions, limited resources and competing objectives will likely mean that compromises will have to be made among stakeholders. Furthermore, the availability of data to capture the potential effects of multiple actions, threat interactions, and compatibility of uses remains a technical barrier even for single realm plans, but methods such as stakeholder interviews to capture traditional ecological knowledge (Ban et al., 2009) and expert elicitation (Martin et al., 2012) can help fill data gaps. Approaches such as scenario planning (Peterson et al., 2003) and simulation modelling (Gurney et al., 2013) can accommodate incomplete knowledge and thus facilitate cross-realm planning even when data is missing or uncertain.

3.2. A new operational framework for applied cross-realm planning

We propose a novel operational framework that incorporates considerations relevant to achieve full integration of planning across realms and offers practical guidance to decision-makers (**Figure 4**). Our framework was broadly based upon leading systematic conservation planning frameworks (Groves et al., 2002; Lehtomäki and Moilanen 2013; Pressey and Bottrill 2009), particularly those relevant to cross-realm integration (Adams et al., 2014a; Álvarez-Romero et al., 2011; Klein et al., 2010), while considering key operational aspects conducive to implementation (Knight et al., 2006).

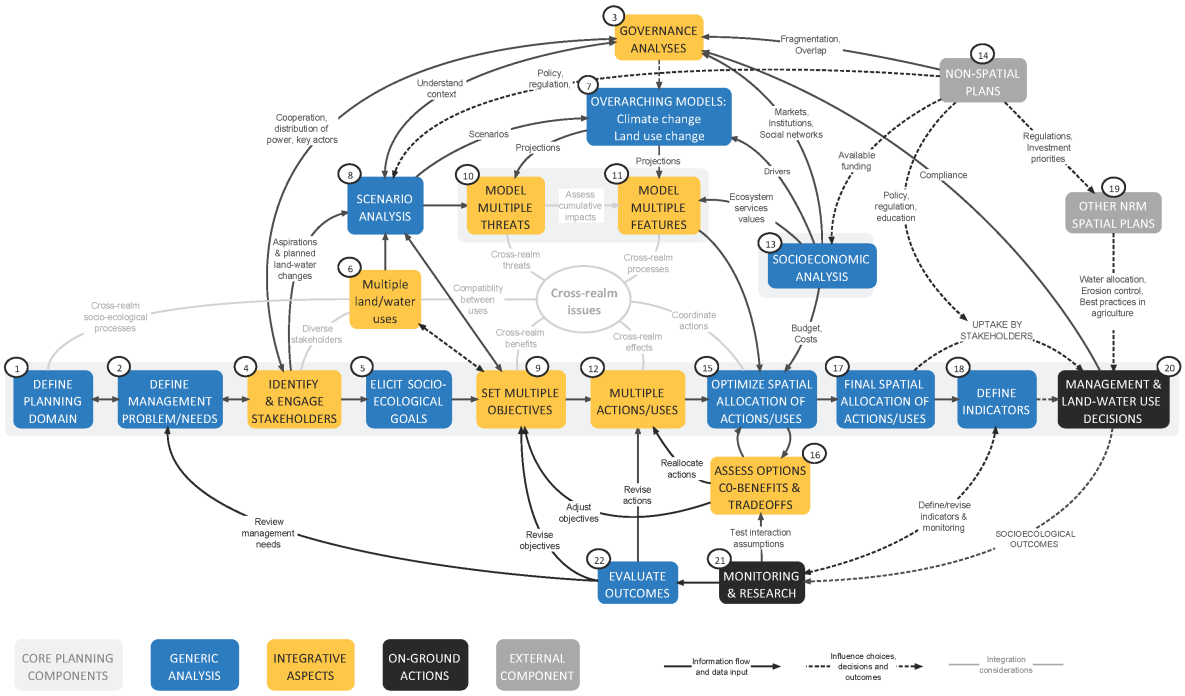

Figure 4. An operational framework to guide integrated cross-realm planning. The framework addresses decision-makers' requirements for a conceptualisation of the steps and processes involved in integrated planning. It also recognises the types of analyses available, such as scenario planning and cumulative impact assessments, and the appropriate points in the planning process to consider these analyses. Some components are common to single-realm planning exercises (blue), while others were identified as critical integrative components (yellow) that will require significant changes to current planning. External components (grey), such as strategic NRM plans, legislation, and current best-practice guidelines, will influence planning through policies, regulations and funding opportunities enabling or constraining management, but can also be

the starting point of planning (e.g. policy mandate). Numbers suggest a sequence of planning components, but the order in which these are undertaken (and their inclusion/exclusion) can change with planning aims, context and resources. Feedback arrows indicate where later stages can generate information that will allow revising, adjusting and/or reviewing analyses and decisions, which will lead to refining plans. This reflects the adaptive management approach identified by decision-makers and the literature as critical to cope with limited knowledge about social-ecological systems (particularly regarding cross-realm processes), ongoing attrition of assets, and emerging management opportunities or constraints (Grantham et al., 2009; Pressey et al., 2013). Designing adequate indicators and monitoring programs is thus essential to assessing the social-ecological outcomes of management interventions required to adjust plans.

The framework in **Figure 4** reflects the key considerations that decision-makers (**Supplementary Figure 1**) and the academic literature identified as fundamental components of cross-realm planning (**Figure 3**), but provides an in-depth and sequential conceptualisation of the information and analyses required to move from single- to cross-realm planning. The core planning components (**Figure 4**, from defining the problem through to implementing management) reflects activities that most decision-makers currently undertake for single-realm planning. Expanding to planning across realms requires enlarging core components to include integrative analyses, as well as undertaking additional integrative components. Below we discuss the aspects of our framework that decision-makers identified as requiring major changes to current planning approaches to achieve integration. For a description of each planning component and its application see **Supplementary Table 2**.

Engaging diverse stakeholders and understanding the governance context

Expanding across realms extends the stakeholder base, as well as expanding governance arrangements. Governance analyses are generally not used in single-realm planning, but can be critical in cross-realm planning to understand the added complexity of institutional arrangements and policies with which planners have to work to facilitate implementation (Dale et al., 2014). Collaborating with institutions that bring together multiple stakeholders (e.g. catchment management organisations) can facilitate engagement with relevant stakeholders to better understand aspirations, commercial and traditional uses, and management problems across realms. Taking advantage of existing (or promoting) institutional partnerships can thus facilitate collaboration, communication and consensus-building among diverse stakeholders and across jurisdictions (e.g. Gouritz Initiative: http://www.capeaction.org.za/index.php/resources/2-uncategorised/70-gouritz-biodiversity-corridor). Identifying who these stakeholders are and how they interact to influence uses and management decisions might require additional studies (e.g. social network analysis: Mills et al., 2014).

Integrating multiple objectives, threats and actions across realms

Management objectives for single realms have been well described (e.g. maintain species populations, represent habitats, increase production); however, objectives for multiple realms are less often described and applied (e.g. protect representative marine and terrestrial habitats while also reducing land-based threats to the marine environment: Klein et al., 2014). Likewise, cross-realm socioeconomic objectives are generally missing (e.g. achieve land development and coastal-marine fisheries goals through catchment management and land/water use practices that minimise downstream impacts). Objectives associated with multiple realms will influence the allocation of actions across realms based on an understanding of cross-realm threats and ecological processes (Stoms et al., 2005), and the costs and benefits of different land/water uses to stakeholders in different realms (Bohnet et al., 2011). Integrating these components represents a major divergence from standard processes and requires new types of decision-support tools and analyses. For example, scenario planning (Peterson et al., 2003) can allow for the envisioning of multiple futures that include different impacts of threats on assets and actions on threats, and thereby inform variable achievement of explicit objectives by feasible actions/uses. In considering multiple threats operating across realms, an understanding of interactions and cumulative impacts of threats becomes critical (Weber et al., 2012).

Assessing management co-benefits and trade-offs

While there are co-benefits and trade-offs involved in any allocation of actions under a constrained budget, consideration of actions across realms results in a more complex decision space (Hermoso et al., 2012). To quantify co-benefits and trade-offs, it is necessary to have an understanding of how different assets respond

to potential actions and whether these responses might interact. Response curves can then be used to optimise allocation of actions to maximise benefits across multiple realms and minimise potential negative effects (Adams et al., 2014a). Given that management actions can affect linked realms differently, this may result in unintended inequalities in the distribution of costs and benefits among stakeholders (Adams and Pressey 2014). Assessing equity of alternative management strategies is thus an important consideration in trade-off analyses (Gurney et al., 2015). Likewise, assessing the potential co-benefits of actions contributing to the provision of ecosystem services with downstream effects (e.g. catchment management improving coastal water quality) can be used to incentivise stakeholders (e.g. pastoralists) carrying higher management costs (Star et al., 2013). Cumulative impact assessment and scenario planning can also be used in participatory processes with stakeholders to help them navigate complex resource-management decisions. The key requirement for any of these approaches is, at minimum, a basic understanding of how threats and assets respond to management or alternative resource uses. Structured expert elicitation is a cost-effective alternative to supplement limited data on interactions between assets, threats, and actions (Martin et al., 2012).

3.3. Major challenges and future research directions in cross-realm planning

To ensure that the operational framework can be applied by managers, we wanted to elucidate both current approaches to addressing cross-realm considerations (**Figure 3**) and related challenges. The challenges identified by decision-makers (**Supplementary Table 1**) can help to identify needs for research and planning capacity. Some common themes emerged from the group discussions: first, including stakeholders in the process is recognised as a key requirement, but procedures are needed to support effective engagement with the more complex array of stakeholders involved in cross-realm planning; second, most considerations for integration can be addressed at least qualitatively, but a lack of quantitative data and models is a major barrier to cross-realm planning; and finally, many different approaches can be employed for parts of the process of cross-realm planning, but there is no integrated platform for cross-realm planning. These challenges reflect the integrative components of our framework (**Figure 4**) and reaffirm the novelty of expanding planning to incorporate multiple realms.

A continued effort to collect appropriate data that capture cross-realm impacts of both threats and management actions is required to ensure that adequate data and models are available to planners (Adams et al., 2014a). Yet, knowledge about cross-realm processes is limited and planners commonly rely on expert advice and modelling based on information from other systems or geographical locations. This can lead to an oversimplified representation of processes and high uncertainty (compounded across models), which can lead in turn to suboptimal allocation of management resources (Langford et al., 2009). Under these circumstances, sensitivity and scenario analyses can be powerful tools to explore potential consequences of using different parameters, models, and/or management alternatives (Geneletti and van Duren 2008; Rude et al., 2015). Furthermore, because cross-realm planning is in its early stages, most approaches have manipulated existing tools (e.g. Makino et al., 2013) or integrated analyses across multiple tools (**Figure 5**). In rare cases, purpose-built software has been developed, which requires a large investment (e.g. Bohnet et al., 2011; Crist et al., 2013). Purpose-built interfaces are promising developments for cross-realm planning, but should be accessible to decision-makers (with minimal reliance on researchers after appropriate training) and flexible to planning in different contexts.

4. A real-world cross-realm planning application

To demonstrate how the framework can be adapted to real world planning, we describe its application to an ongoing planning process in the Daly River catchment, Northern Territory, Australia. Over the course of the past two and a half years of collaboration with decision-makers we developed and refined the framework, while adapting it to the current development and conservation planning process in the Daly catchment. The Daly catchment covers approximately 5.2 million hectares. The Daly River (including its main tributaries) is itself an important conservation asset, being one of northern Australia's largest rivers, with unusually consistent year-round flow (Kennard et al., 2010). Riparian strips contain some of the most extensive gallery (rainforest) vegetation in the region. The catchment is a high priority for development, with particular interest for its horticultural potential. Consequently, the government identified the need for a plan that integrated priorities for development and conservation, leading to the Daly River Management Advisory

Committee (DRMAC) commissioning an integrated planning process (**Figure 5**: numbers identify components of our framework undertaken in the Daly as described below).

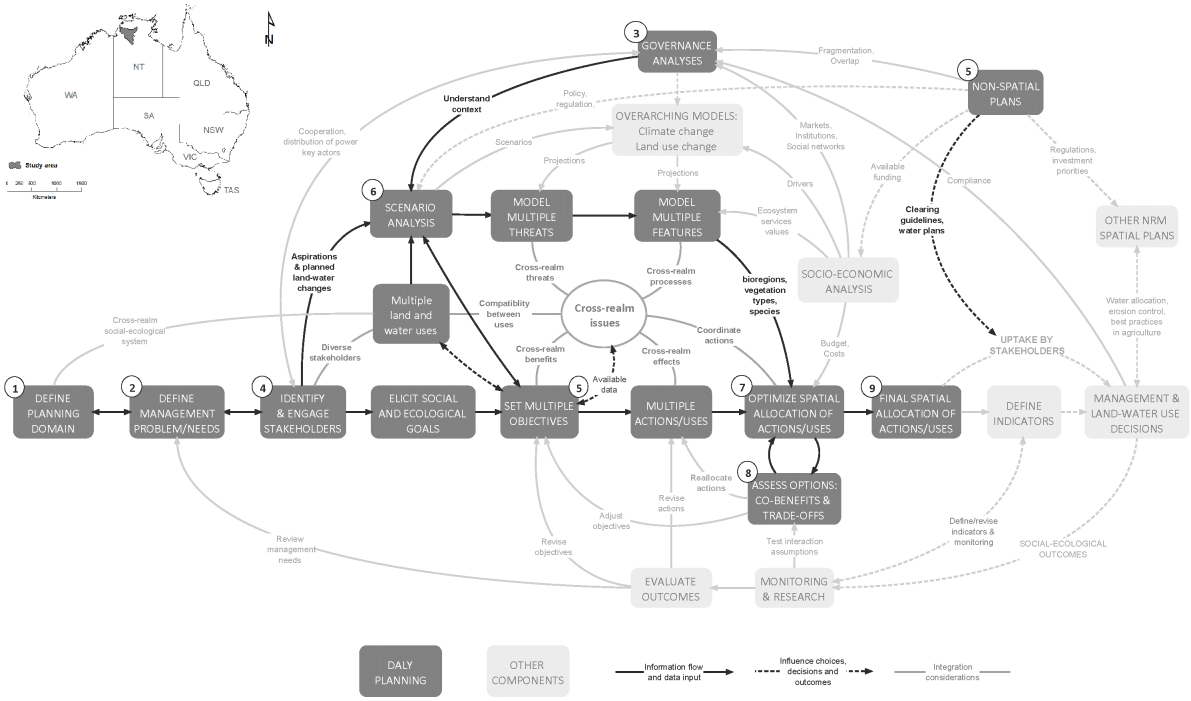

Figure 5. Operational framework application in a planning process in the Daly River catchment, Northern Territory, Australia. Numbers correspond to key stages discussed in the text. For a full description of each stage and specifics for the Daly catchment plan see **Supplementary Table 2**.

The planning domain was defined as the Daly catchment, including terrestrial and freshwater systems (1), given this is the region which DRMAC is tasked with providing advice for resource management decisions. (2) The planning process was initiated with a feedback session between DRMAC and researchers, leading to a clear problem statement and the decision to design a strategic spatial plan for development and conservation. (3) A governance analysis was conducted to understand the overall context for the plan, and to identify strengths and weaknesses in natural-resource management that should be considered during planning (Dale et al., 2014). (4) Engagement of stakeholders aimed to raise awareness among the catchment's residents of the planning process and elicit preferences for different aspects of life in the catchment to inform objectives (for full description of objective setting and engagement process see: Adams et al., 2014b). (5) DRMAC identified qualitative goals with a series of internal discussion sessions. Based on these goals, all available data on relevant spatially-discrete assets were compiled and presented to DRMAC. A final discussion session used the goals and data to identify quantitative spatial objectives for both terrestrial and freshwater realms (e.g. protect 17% of terrestrial habitats – in this case vegetation types – and 17% of freshwater species distributions). The plan excluded objectives for downstream marine values as there were no marine conservation features identified by the stakeholders. The objectives reflect existing policy, such as government commitments to international policy on protected areas (CBD 2010), relevant legislation, and previous plans to inform uses of land and water (e.g. clearing guidelines: Adams and Pressey 2014), or the views of experts and other stakeholders. The plan used sub-catchments as the planning units to facilitate inclusion of connectivity of freshwater systems and to meaningfully interface with the water management tool. (6) Stakeholder engagement highlighted potential ranges for several objectives (e.g. land-clearing levels). Therefore, six scenarios were developed based on sets of objectives reflecting two plausible clearing levels (10% and 20% of the catchment) and three mixes of agricultural land use on cleared land. (7) With objectives in place, the planning team used a decision-support tool (i.e. Marxan with zones: Watts et al., 2009) to generate alternative configurations of land uses that achieved objectives for conservation and development in each scenario at lowest cost. (8) The current stage involves coupling of land-use scenarios with water-use for agricultural land, and then assessing potential impacts, co-benefits, and trade-offs, supported by a tool for evaluation of management scenarios developed for the Daly (Stoeckl et al., 2013). (9) The current assessment was intended to inform adaptive planning for land and water uses in the catchment

guided by DRMAC. However, in 2013, the government chose to discontinue support of DRMAC. Consequently, the ownership of the plan, government buy-in, and institutional arrangements for implementation are uncertain. While the discontinuation of DRMAC means that the original implementation strategy is no longer feasible, the plan has enduring value in that it provides a set of goals, objectives, and related priorities for the catchment, relevant to local stakeholders, that can be used by the appropriate NT Government departments or newly formed Territory-wide catchment advisory committee (NTCAC) if policy agendas were to shift to create opportunities for implementation (Moon et al., 2014). Other funding mechanisms such as carbon offsets can provide financial opportunities for implementing components of the plan (e.g. priority areas for savanna burning, a carbon abatement method). The plan could also be used by non-government organizations such as natural resource management groups and environmental NGOs to guide investment in environmental management in the catchment.

5. Conclusion

For plans to be effective, they must consider socioeconomic and ecological considerations across realms. We developed an operational framework for cross-realm planning that reflects the full scope and complexity of planning for multiple interconnected realms. The framework describes how requirements for cross-realm planning can be implemented in real-world planning and thus can guide planning for implementation. Our operational framework builds on existing best-practice guidelines, but also aims to close the gap between research, planning and implementation through the direct participation of decision-makers in the framework's design and application. While there are still major knowledge gaps and a need for software advances to support cross-realm planning, we hope that the framework will help planners to continue the transition to applied cross-realm planning.

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