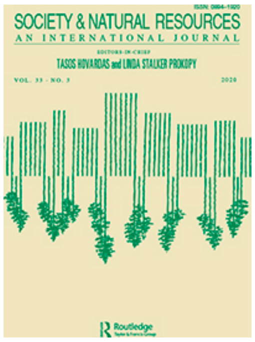

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Addressing Integration Challenges of Interdisciplinary Research in Social-Ecological Systems

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ABSTRACT

Conducting research on coupled social-ecological systems (SESs) presents inherent challenges, such as coordination across disparate disciplines or integrating across multiple scales and levels of governance. To overcome these common challenges, we propose that structuring the research design itself according to SES principles provides for integrative execution of SES science. First, starting with pilot work, human and natural science researchers should work as a team to identify and access multi-level entry points (i.e. points of direct engagement) within the system, relative to the spatiotemporal scales under investigation. Second, teams should implement an adaptive process that begins with the proposed research design and uses shared experiences from pilot work to refine protocols prior to subsequent data collection. We provide examples of multi-level and multi-scale entry points, and show that adaptive management of research design through coordinated iteration allows for better research integration and applicable outcomes.

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Adaptive management; cross-scalar; interdisciplinary; research design; research entry points; social-ecological systems

Introduction

While development interventions recognize the importance of collaborative, cross-scalar and interdisciplinary work in social-ecological systems (SES) (cf. Bodin 2017; Sachs 2012), academics engaged with SES initiatives still find methodological challenges (Wilson et al. 2010; Stringer and Dougill 2013) despite extensive work recognizing the necessity of an SES approach to researching systems dynamics (Chen 2015; Gibson, Ostrom, and Ahn 2000; Fischer et al. 2015). SES researchers should adopt an "ideology in practice" (Fine and Sandstrom 1993) standpoint and explicitly use the dialectical role of knowledge (Berger and Luckmann 1991) to counteract the secondary socialization of individual disciplines (ibid.). In so doing, SES researchers can create an integrated

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research design that is itself framed directly on SES concepts, while simultaneously building a community of practice (Wenger, McDermott, and Snyder 2002) through shared academic principles.

In this paper, we discuss one path for how an interdisciplinary team can embed systems-informed principles such as multi-scale points of direct engagement with different levels and types of stakeholders and organizations (entry points) and iterative design into the research framework itself. We posit that doing so supports more integrated research outcomes and ensures that research results are effectively incorporated into decision-making and governance processes at the system level. We suggest that learning from SES development work (Schneider and Buser 2018) as well as examples from other disciplines (cf. Bell, Shaw, and Boaz 2011) can improve the impact and uptake of scientific findings (Lang et al. 2012). We also aim to contribute towards better collaborative approaches in SES science to improve environmental governance and sustainability specific for transboundary regions where scale and human-environment interactions are implicit to successful development plans (Bodin 2017). We use experiences from a multi-year field research campaign in southern Africa to illustrate the utility of articulating a research project—and not only the subject being studied—from an SES perspective.

Background

SES research should be highly interdisciplinary and requires scientists, scholars, and practitioners to address the dynamic intersection of the social and ecological scales and issues being examined, and to account for the constraints and challenges these various scales and participant inputs introduce. SES research endeavors often have interdisciplinary objectives aimed at understanding the complexity of a given SES (Chen 2015; Gibson, Ostrom, and Ahn 2000; Stringer et al. 2017). In practical terms, academics working at the interface between the social and ecological systems and across multiple spatial and temporal scales already wrestle with multiple research management challenges, including framing research questions and approaches with terminology common to multiple disciplines and managing large research team dynamics. Yet to address such complexity, researchers often retreat to their own disciplinary spaces (Max-Neef 2005), compartmentalizing the research project for later 'reassemblage' and analysis, typically following a positivist 'closed system' approach (Barton, Stephens, and Haslett 2009). While transdisciplinary research is still seeking its own key design principles (Lang et al. 2012), some of the core principles needed for successful SES research development (cf. Holling 2001; Fischer et al. 2015) and implementation can equally be applied to research frameworks. Consideration of the underlying structure of a research design using terms of system principles strengthens an executable plan by ensuring data collection and analyses will unfold iteratively, at multiple scales and feedback into the system at multiple levels. The principles behind systems thinking can be applied conceptually to the design of interdisciplinary research in order to address integration challenges, provide greater applicability for decision-making and enhanced durability in interdisciplinary research relationships (Table 1).

Table 1. Application of SES principles to research design.

Core principles	General application in SES literature	Application of principles to SES research design
Diversity	Livelihood and biological diversity as source of adaptive response and stability (Low et al. 2003)	Disciplinary diversity through interdisciplinary team and combination of academic and practitioner team members. Inclusion of collaborators from local socio-political contexts (cf. Shibata et al. 2015; Nassl and Löffler 2015)
Multiple temporal and spatial scales, structural complexity, hierarchy	Multiscalar and multidirectional feedbacks in complex systems that include both humans and environmental components they depend on (Pollard and Du Toit 2011; Walker et al. 2004)	Research at multiple scales, in both data collection and data analysis; structural complexity and hierarchy in SEM approach. Allows for greater integration, and clearer understanding of context and components.
Feedback loops and cross-scale feedbacks	Cross-scalar interactions and system dynamics (Cash et al. 2006; Gibson, Ostrom, and Ahn 2000; Holling 2001)	Capturing of feedback through iterative research process, and articulating interactions between indicator variables and higher order latent characteristics. Opportunities for 'open system' approaches and learning (cf. Barton, Stephens, and Haslett 2009)
Emergent properties	Functioning systems of interdependence arising from interactions between individual humans and the specific natural resources in their environment (Levin et al. 2013; Chave and Levin 2004)	Research outputs arising from interdisciplinary research, emergent patterns from statistical analyses. Ensuring outputs are less limited by disciplinary bias.
Adaptive co-management and multiple interactions	Integrating pluralism of voices and varied stakeholder inputs in adaptive co-management and governance (Gunderson and Holling 2002; Brondizio, Ostrom, and Young 2009)	Co-design and flexibility from proposal to execution. Communication flows and relationship dynamics both within the research team itself, as well as with stakeholders and other project collaborators (cf. McGreavy et al. 2015)
Uncertainties and non-linearities	Large-scale variabilities, abrupt thresholds, regime shifts (Ludwig, Hilborn, and Walters 1993; Grêt-Regamey et al. 2014)	Accommodating tradeoffs and underlying assumptions for each analytical requirement in context of limited project budgets and timelines.

Below, we present different considerations encountered in the process of transitioning, as an interdisciplinary team, from the stage of a successful award to studying a multi-scalar SES in southern Africa. We begin with a brief discussion on the complexity of engaging in interdisciplinary research and then discuss the research design, data collection, and stakeholder collaboration stages through explicit examples drawn from our experiences. We emphasize that research teams can be as complex and challenging as the SES studied making it necessary to approach ideas for entry points and integration of science goals as an integrated process within the team itself.

Complexity in Social-Ecological Systems Research Design

In conducting interdisciplinary, cross-scalar SES work, researchers must develop a set of guiding principles for internal engagement and communication to ensure their research design balances the various tradeoffs among disciplinary biases, analytical scales, and levels of system organization. Building off principles presented in Table 1, additional considerations include the co-development and co-evolution of objectives, accounting for uncertainty, cross-scalar interactions, and power dynamics, and possessing critical awareness (Gunderson and Holling 2002). The internal communication dynamics and management of research teams, for instance, weekly, Skype meetings, use of collaborative project management platforms (Slack), monthly email updates that delegate and assign tasks, face-to-face multi-day workshops, are critical yet often overlooked components that complicate SES work (McGreavy et al. 2015). Expanding upon these internal, research-design and communication principles, when engaging externally with stakeholders, balancing conflicting priorities over the same area of focus, responsibility when the policy area does not match the problem area, and land tenure are also sensitive issues when working in complex SESs (Gordon, Peterson, and Bennett 2008; Vance and Doel 2010).

Central to research design and communication is the question of *scale*. We define scale as the spatial, temporal, quantitative and analytical dimensions employed in the process of studying and modeling an SES (Turner, Dale, and Gardner 1989, 246; Mayr 1982, 65; Allen and Hoekstra 1990). For example, spatial and temporal scale of examination can define any research program. We differentiate between the terms "scale" and "level" following the nomenclature set by Gibson, Ostrom, and Ahn (2000), that level is a unit of analysis that falls along a scale. Scaling considerations apply to both biophysical and social dimensions at different levels of analysis, thus making scale a critical baseline component for successful research design. In terms of spatial scale, a research program may examine socioeconomic characteristics at household, community, and regional levels (Figure 1). Similarly, the concepts of grain and extent that relate to the finest unit of analysis and area or population of interest, respectively, can apply to all SES components, and early consideration of these characteristics in research design is critical for aligning different disciplinary and participant inputs.

When applied in interdisciplinary settings, multi-scalar approaches present a high potential for inference and transferability to other empirical and applied research questions. To successfully embed system principles into a research framework and navigate common challenges in conducting SES work, teams should commence with the understanding that the communication and collaborative processes research teams implement intrinsically inform and influence further interactions in larger SESs and can greatly influence overall research success (Shirk et al. 2012; Stokols, Lejano, and Hipp 2013; McGreavy et al. 2015). When an interdisciplinary team sets out to tackle a multi-year project aimed at integrating social and biophysical inputs, contributions and needs from stakeholders at multiple and levels of analysis, iteration and integration between and among components and scales are key (Figure 2).

In our case study SES research project, we examine the interface of household level vulnerability, land use activities and environmental variability within the Kavango–Zambezi Transfrontier Conservation Area (KAZA TFCA) region in southern Africa. Specific to the research design objectives, we rely on multi-scale entry points for conceptualizing the inherent multi-scalar feedbacks between humans and their environment. We take an iterative approach for understanding scale considerations in the research design and implementation (Figure 2). We advocate for these two critical aspects when approaching scientific engagement in a region such as the KAZA

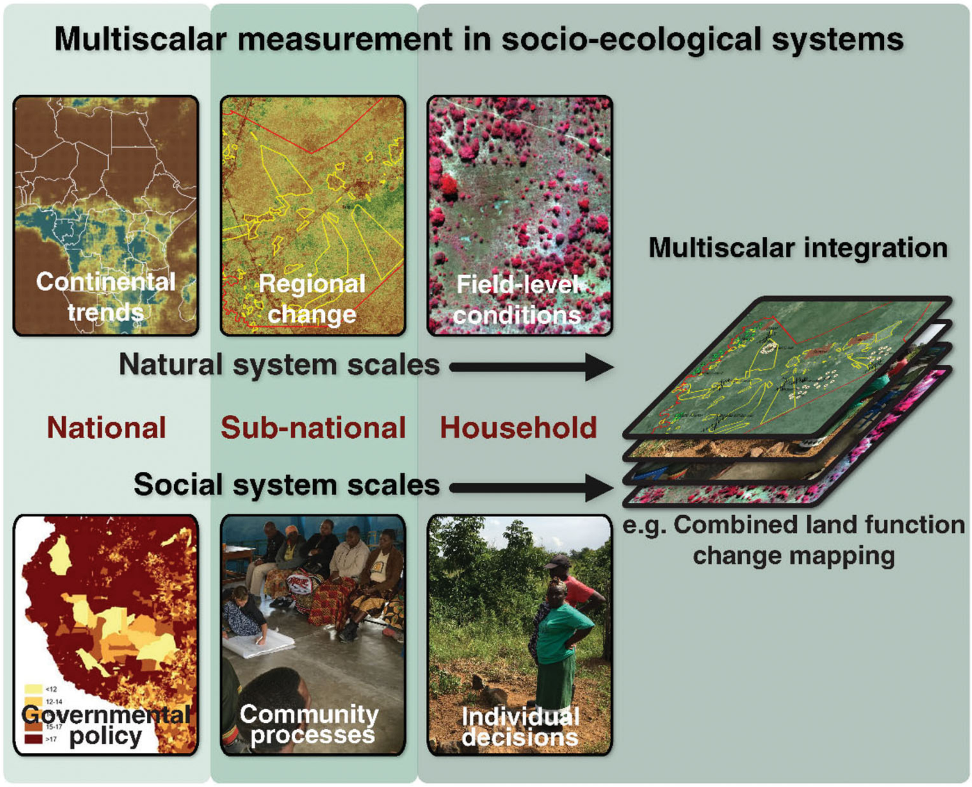

Figure 1. Multi-scalar integration of social and environmental scales in SES research design.

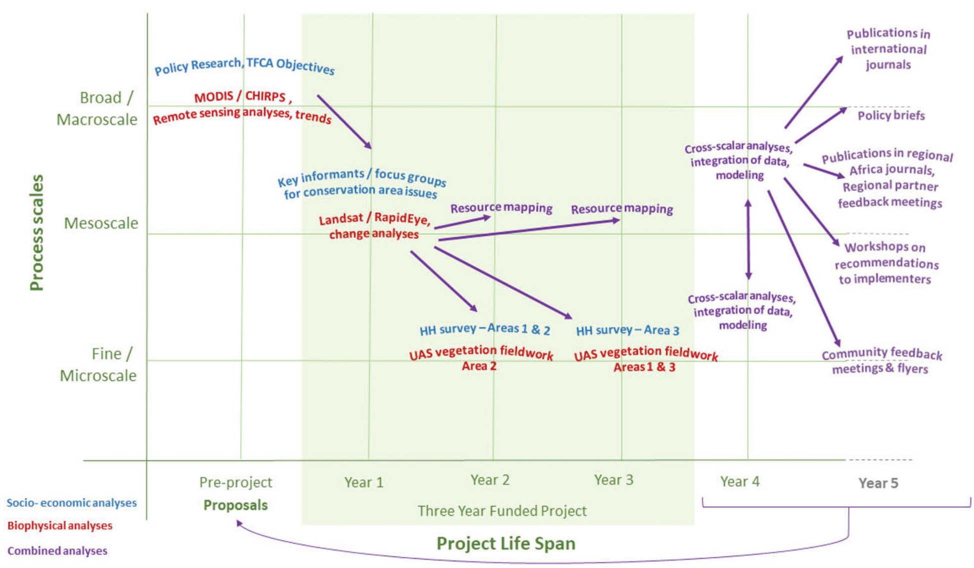

Figure 2. A visual timeline of socio-economic and biophysical assessments showing cross-scalar and transdisciplinary feedbacks and linkages in the process of adaptive, iterative research design. The project life span highlights an example of average timespan for a US-government funded research initiative.

landscape which spans 6° of latitude, capturing not only a biophysical gradient (Pricope et al. 2015) but also significant socio-economic variation associated with different stakeholders, national governance and land-use patterns.

Case Study: Multi-Scalar Feedbacks and Research Design in the KAZA SES

The KAZA landscape includes a disconnected network of protected areas interspersed with farms, rangelands, and urban areas across Namibia, Botswana, Angola, Zambia, and Zimbabwe. The TFCA, managed by the KAZA Secretariat with equal representation by the respective countries' wildlife, environment, and tourism government departments, is a regional initiative aimed at economic and tourism development balanced with conservation goals (Cumming 2008). Its governance system is layered over individual country systems and country-specific interests (in wildlife, environment, and tourism) resulting in inherent occasional conflicts. Further, country-specific traditional authorities, community-based organizations (CBOs), and non-governmental organizations make management across scales a challenge in cooperation and communication.

Given their complexity both socio-ecologically and in terms of management of trade-offs and outcomes between community development and natural resources conservation, we use three community conservation areas as an exemplar SES: Chobe Enclave in Botswana (Pop: 4128, Area: 2990 km^2), Mashi Conservancy in Namibia (Pop: 4300, Area: 298 km^2), and the Lower Western Zambezi Game Management Area (Pop: 70,157, Area: 38,070 km^2) in Zambia. These areas represent places where team members have collaborated with local institutions and collected previous data over multiple years or were identified by local, in-country collaborators.

Our iterative, multi-scalar process for designing a field-based protocol included interdisciplinary engagement and exchange within the research team as well as integration of ideas from local collaborators and community members regarding the proposed research design. The latter was important to ensure that the development of the multi-scale scientific approach to studying the KAZA SES and resonated directly with the hierarchy of stakeholders making decisions within the SES.

Field Implementation: Iterative Research Design at Multiple Scales and Levels

In the process of research design, our team conducted initial assessments that included both biophysical reconnaissance and conversations with district- and village-level officials, traditional authorities, and representatives of the CBO in each country. Importantly, during this initial stage, we sought appropriate permissions and followed cultural protocols to operate in the area. We conducted key informant interviews aimed at eliciting input to inform a household survey instrument, and conducted group interviews with individuals selected in consultation with village leaders.

To illustrate the *diversity, structural complexity and multiple spatio-temporal scales of the research design*, we explicitly framed the social context through the lens of national policy agendas (Figure 2). Policies highlight regional differences and national priorities and provide coarse comparisons of differences in governance. Of particular interest were differences in the approaches supporting community conservation and the degree to which communities in each of our focal areas have rights to make natural resources management decisions. Our assumption was that the formal policy environment is constant for an extended period for all communities within any country, but differed among countries. For example, Botswana has a centralized, bureaucratic and wealthy government whose one-size-fits-all policies do not take into account local variation in ecological or cultural conditions, and there is limited devolvement of environmental decision-making to the local level. In contrast, Zambia has fewer governance resources available for a larger area and greater population, resulting in stronger local control by village authorities, but less certain adherence to laws and standards.

Once the broad-scale socio-political setting was understood, our research shifted *hierarchical and spatial scales* to focus on socio-economic variability at the mid-level, within each community conservation area. This was done through key informant interviews with individuals tasked with addressing issues at the district or community level. Key informants provide valuable insights from within the system; they hold knowledge not only of the systems where they live and work but also of their role in these systems—what is sometimes referred to as "lived experience" (Bernard 2002). These roles are critical to identify early on in research to ensure appropriate information flows and more effective uptake of research findings beyond the project lifespan. Our key informants represented perspectives from a range of sectors (e.g. agriculture, wildlife, tourism) as well as from different social sectors (e.g. traditional authorities, NGOs, district officials). Interviews and discussions were structured within the national policy context and directed toward land use zones and the dynamics of biophysical processes across the conservation area. We met with the KAZA Secretariat for the regional, landscape level overview of conservation activities and engaged with central government officials from each of the three countries. Exchanges focused on oral histories, general orientation, local issues related to natural resource and wildlife management, sharing of knowledge of ongoing and completed projects members of the team had undertaken with prior support. This dialog gave us the concerns and priorities for each country's area, allowed us to share our past research insights and helped build mutual trust. Comparing these priorities among the nations reiterated key differences in policy goals and implementation effectiveness, highlighting the challenge of balancing *different perspectives, emergent properties, and cross-scalar feedbacks* and the need to incorporate these into SES research design.

Moving *hierarchical and spatial scales* to the community level and striving to maintain the *diversity of perspectives and voices* in the design process, we held group interviews with men and women during initial field visits. Small discussion groups that address a specific topic are a well-established tool for understanding perspectives and priorities at this level (Slocum et al. 1995). Guided discussion focused on multiple topics: the large-scale environmental threats to livelihoods, such as droughts and unpredictable flooding; the challenges of village life, such as sharing the landscape with wildlife and the distribution of land uses such as fields and resource collection areas; and the more household-level challenges, such as the types of natural resources that many people depend on, such as firewood, fish and thatching grass. Interviewees touched on both social and environmental issues, while also moving from landscape level—where resources are located—to household level—where resource consumption takes place.

Importantly, respondents also referred to the formal and informal rules and institutional arrangements at all levels—such as agreeing where resources should be collected in a year depending on the season, the challenge of new-comers not following rules, and the legal and economic constraints of linking the harvesting of resources to outside markets.

With these understandings in place, in year two, we were then in a position to pursue the next research activities—mapping out where households collect resources, which is also a mesoscale assessment, and implementing household surveys. Household surveys were the largest socio-economic dataset, capturing variation at fine spatio-temporal scales, and informing *emergent properties and differences across SESs*. Resource mapping, delineating the areas where specific resources are gathered by a community, brings the biophysical and socio-economic analyses together spatially and across multiple temporal scales of remote sensing data analysis. The focus on natural resources is an important one in SESs in developing countries. The concept of "resource" is the point where a feature or aspect of the biophysical environment overlaps with socio-economic strategies pursued by community members. Working with key informants, we mapped the boundaries of known resource collection areas, and what resources they were important for.

Since our research ultimately seeks to understand the patterns of livelihood adaptations, we moved to the fine scale to measure socio-economic variations at household levels. Randomized representative samples from each country's selected conservation area provided a set of 720 records of rural household characteristics: demographic composition, assets—particularly those that represented tools for different livelihood strategies, income sources and quantities, extent of reliance on natural resources, and distance to those resources—and place names for resource collection areas for linking back to the resource mapping exercise.

The household surveys and resource mapping were matched by integral ground-based biophysical assessments of different land covers and vegetation productivity as they intersect with various land and resource uses. Here we used a *multi-temporal and spatially hierarchical approach* relying on remote sensing products at different management scales aimed at obtaining an expeditious view of the effects of human use, management and environmental variability and change on the natural resource base (Figure 2). We worked with multiple landscape scales, with different resolutions and extents of remote sensing imagery (e.g. MODIS, Landsat, RapidEye) to assess landscape level conditions (such as dynamics of disturbance regimes including recent fire events, fire history, flooding, vegetation response to precipitation through vegetation indices). This was supplemented by a visual analysis using Google Earth to establish village and community extents and grazing piospheres and to glean information about land use histories across institutional gradients.

Secondly, we gathered reference data and in-field estimates of vegetation structure, composition, diversity and vegetation biomass to train imagery analyses and for dependent data in modeling. These dependent data and constructed models, along with information from the resource use areas and household data, provide the information needed to link and subsequently scale relationships between social and ecological components of the SES and create integrative research products. Ensuring that all components of data collection are complementary represents one of the largest hurdles to

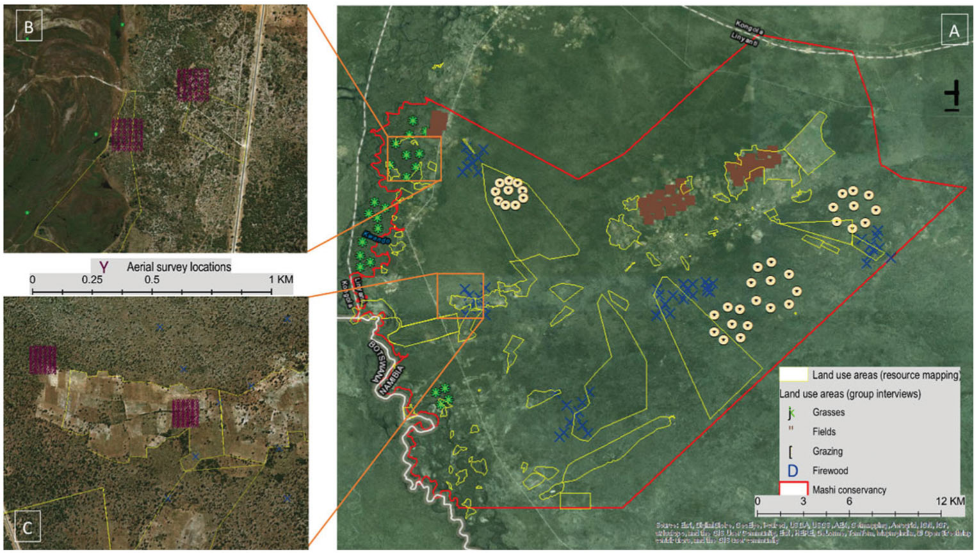

Figure 3. (A) The convergence of information elicited during two stages of research (initial field visits and data collection campaigns) at different organizational scales: focus group interviews (general land uses) and key informant and household-level interviews (the resource areas outlined in yellow). (B and C) Examples of spatial overlap among the land use areas delimited from surveys and biophysical data collection (showing UAS survey footprint in purple).

successful SES study implementation. To illustrate schematically what that integration entailed, Figure 3 highlights spatially explicit information on resource use elicited at multiple scales (focus groups and key informants) in Mashi Conservancy.

The iteration across years allowed the transfer of transcribed community interview information collected by the sociological researchers to the biophysical scientists for spatializing, using GPS technology, the resource areas (Figure 3A). The aggregation of household level information (area names and other metrics) was used to accurately delineate the location of the areas for the subsequent biophysical assessment using ground and aerial UAV surveys (Figures 3B,C).

It was only by *iteratively and adaptively managing information collected using hierarchical entry points at multiple spatio-temporal scales while accounting for emergent properties, feedbacks, non-linearities, and uncertainties conducted in partnership among the social and biophysical team members and local collaborators* that various system facets began to connect to each other in the research design. Resource collection areas are integral to securing livelihoods in the KAZA region, yet determining their location and extent is a complex task. We were able to successfully map resource areas by combining social data (i.e. local names and descriptions) elicited from the community during group interviews and household surveys, followed by the individual knowledge of key informants, and complemented by geospatial management and mapping of the data. Managing the data in a spatially explicit manner is necessary for the integration and statistical formulations that rely on field data and are subsequently coupled with remotely sensed data products. In-field coordination of the interdisciplinary research team (achieved by morning planning an evening debriefing meetings and careful orchestration of tandem social and biophysical data collection activities and field logistics) is vital to the success of linking the different levels of land use activities in such a way as to design an effective social survey instrument and capture the necessary land use information needed to relate to the remotely sensed land cover dynamics. Regardless of prior knowledge of a given system, close partnership and communication across team research scientists and local collaborators greatly improve the potential to successfully link across different components of larger interdisciplinary initiatives.

The research team must constantly engage with each other both while planning for and during data collection implementation phases to ensure social and biophysical datasets are linked in a sequential step-down in an analytical scale (Figure 1). In addition, based upon outcomes from both initial key informant interviews (e.g. with the KAZA Secretariat) and focus groups (i.e. within communities), we observed that the entry point level of engagement can greatly influence the perspective of SES research development and ultimate outcomes. By working with *multi-level entry points*, researchers can position their research to triangulate different intervention measures, reaffirming the position that approaches that result in both actionable outlets and scientific advancement are preferable to those that focus solely on academic findings. In KAZA, typically for NGOs and government representatives, the conversation may focus on conservation and development whereas if the entry point is an on-the-ground key informant or focus group with community members, the conversation is much more likely to focus on livelihoods or daily lived realities.

Anticipating Challenges in Social-Ecological Research Design

Depending on desired outcomes and motivating questions, SES research uses multi-scalar entry points into conceptualizing and beginning to disentangle the feedbacks between humans and their environment. This multifaceted approach to engaging with issues in an SES is especially relevant for regions that include smallholder communities where the dependence on agro-ecosystems is arguably the most direct, and where access to and ownership of land and resources are often contested (Nelson 2010; Duffy 2006; Ribot and Peluso 2009). These inroads, or entry points, come with bias and assumptions based on a research team's connections, system perspectives, and opportunities. However, we argue that the open acknowledgement of the underlying criteria and motivation that drive the entry point decision-making is another important layer of information when examining multi-scalar questions and moving from research design to execution.

Specifically, we found that engaging in iterative processes throughout research design and implementation can greatly ease the full engagement of appropriate stakeholders at all levels of influence in the management of an SES, from the smallest levels of social organization (village, community, town) to government-level sanction and support. In this case, stakeholders included in the process are both subjects of, and participants in, research and, as such, it can be especially difficult to get national and district officials to value the importance of a multi-scalar approach. In our work, we have attempted to address this challenge by presenting clear descriptions of the overarching research goals and potential benefits targeted in explicit terms at each scale of analysis. Generally, we found that it was difficult for stakeholders and other research participants to appreciate the iterative nature of the research, where there are repeat visits to their area that incorporate feedbacks from earlier interactions without seeing any immediate, tangible results or benefits. We have tried to address this by ensuring that we circulate interim policy briefs and publications to all key informants, stakeholders, and collaborators who are not part of the core research team.

One of the most onerous challenges overall when working in complex SESs remains balancing focus across scales, particularly when cross-scalar processes require multiple scales of analysis. For instance, questions about broader scale issues may seem constant at a fine scale and therefore seem irrelevant to household respondents in a survey, whose resultant irritation could undermine response quality. Conversely, when beginning to collect data at the fine scale, identifying indicators of environmental change that are specific to and applicable at the local context, but can be equally generalized for comparison across the whole landscape is similarly laborious. In order to mitigate for some of these challenges, we argue that repeat visits that explicitly incorporate explanations and feedbacks in the form of information already acquired at other scales and levels of system organization help build a legacy of system memory, knowledge, and mutual trust. Other challenges when working in complex SESs revolve around accounting for inter-annual variation in biophysical or socio-economic conditions and adjusting for specific or anomalous conditions (e.g. flooding, late or erratic start of the rainy season, household drought relief handouts, changes in conservation or other policies) that occur during one or more field visits, but may not be typical of the longer-term trends or relationships that are being researched. One of the best approaches to handling the issue of surprises or anomalies in the functioning of an SES consists of ensuring reliable and timely streams of information from in-country collaborators or near real time monitoring of biophysical and socio-economic conditions and situating field results in the context of longer time-frame datasets. Finally, another challenge one might anticipate is that not all funders would be amenable to flexible research design, even if teams commit to the provision of interim outputs and we recommend teams ensure they have appropriate flexibility in project implementation and reporting.

Conclusions

Complex societal problems at the human-environment interface require more flexible, dynamic and interdisciplinary research approaches to inform policies and adaptation strategies that are useful at multiple scales. To better address this complexity, we suggest that research should itself take a scale-based adaptive and iterative approach and that SES principles be explicitly integrated into project processes, starting with the research design phase. To illustrate how we embed system principles into the research framework itself and how we navigate common challenges in conducting SES work, we started from the understanding that the communication and relationship-building processes research teams implement intrinsically inform and influence further communication and interactions with the larger SES. We built on that literature by providing a case study perspective at a regional, transboundary scale following the call launched by Bodin (2017) and Zscheischler, Rogga, and Busse (2017) that for collaborative, transdisciplinary SES work to be increasingly effective, regional scale work should be highlighted more. Our research process implementation relied on the utilization of multi-level and multi-scalar entry points for initial study area assessments combined with multiple iterations through the research design and execution aimed at integrating with stakeholders at multiple scales and levels of analysis, both social and biophysical. Our experiences lead us to recommend a diverse, cross-disciplinary, cross-scalar, iterative and adaptive integration of approaches into the SES research design phase in order to broaden both the scientific and societal impact of research.

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