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Understanding protected area resilience: a multi-scale socioal-ecological approach

G. S. Cumming, Craig Allen, Natalie Ban, Duan Biggs, Harry C. Biggs, David H.M. Cumming, Alta de Vos, Graham Epstein, Michel Etienne, Kristine Maciejewski, et al.

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1 # UNDERSTANDING PROTECTED AREA RESILIENCE: A MULTI-SCALE, SOCIAL-ECOLOGICAL APPROACH
2
3

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26 *Abstract*. Protected Areas (PAs) remain central to the conservation of biodiversity. Classical PAs
27 were conceived as areas that would be set aside to maintain a natural state with minimal human
28 influence. However, global environmental change and growing cross-scale anthropogenic
29 influences mean that PAs can no longer be thought of as 'ecological islands' that function
30 independently of the broader social-ecological system in which they are located. For PAs to be
31 resilient (and to contribute to broader social-ecological resilience) they must be able to adapt to
32 changing social and ecological conditions over time in a way that supports the long-term
33 persistence of populations, communities, and ecosystems of conservation concern. We extend
34 Ostrom's social-ecological systems framework to consider the long-term persistence of PAs, as a
35 form of land-use embedded in social-ecological systems, with important cross-scale feedbacks.
36 Most notably we highlight the cross-scale influences and feedbacks on PAs that exist from the
37 local to the global scale, contextualizing PAs within multi-scale social-ecological 'functional
38 landscapes'. Such functional landscapes are integral to understand and manage individual PAs
39 for long-term sustainability. We illustrate our conceptual contribution with three case studies that
40 highlight cross-scale feedbacks and social-ecological interactions in the functioning of PAs and
41 in relation to regional resilience. Our analysis suggests that while ecological, economic and
42 social processes are often directly relevant to PAs at finer scales, at broader scales the dominant
43 processes that shape and alter PA resilience are primarily social and economic.

44

45 Key words: conservation, cross-scale, resilience, social-ecological system, national park, reserve,
46 spatial resilience

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49 INTRODUCTION

50 Protected areas (PAs) remain one of conservation biology's most important approaches for
51 ensuring that representative examples of ecological populations, communities, and ecosystems
52 are maintained for current and future generations. Historically, most PAs were created as places
53 that would remain 'natural' (Brandon et al. 1998). Over time, as the original focus of
54 conservation biology on rare and endangered species has expanded into a more general
55 awareness of the relevance of ecosystems (and the services they provide) for human wellbeing,
56 our understanding of PAs and their objectives has changed. PAs now range from strict PAs, in
57 which no harvesting of fauna or flora occurs and human visitation is restricted, to multiple use
58 areas in which sustainable use of natural resources is the norm (Table 1; Dudley (2008)). PAs
59 can no longer be viewed as purely ecological islands (Janzen 1983). Instead, as we come to
60 better understand (1) the driving roles of regional processes (i.e., those that occur over broader
61 extents than most PAs) in the composition of ecological communities and their spatial and
62 temporal population dynamics; (2) the complex political and economic influences that underpin
63 PA establishment and maintenance; (3) the role of PAs as providers of benefits for local
64 communities and society within a broader landscape context; and (4) the potential costs of PAs,
65 including opportunity costs, it is becoming increasingly clear that PAs are social-ecological
66 systems that both respond to and influence a wide range of ecological, social, and political
67 processes.
68
69 TABLE 1 HERE
70

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71 PAs are human constructs in which institutions are used to try to achieve ecological and social
72 goals. Human activities in most PAs are limited so that recognized natural, ecological and/or
73 cultural values for some social groups are maintained (Table 1; Dudley 2008). In order to meet
74 ecological goals, conservationists have strived to influence PA location, pattern, management
75 and governance. The creation of state-owned or public conservation areas is usually driven by
76 the ecological consciousness and political will of the participants (Mathevet and Mauchamp
77 2005) but must also confront a variety of ecological and political constraints. Defining the formal
78 boundaries of protected areas is impossible without support from external institutions such as
79 national and international policies, laws, and agreements. This means that the creation and
80 maintenance of PAs is heavily dependent on their compatibility with institutions in the broader
81 social and economic system. Each PA has social and ecosystem characteristics, often including
82 stated management goals, that influence (and are influenced by) governance, affecting economic
83 outputs and social outcomes in the social-ecological system (Ostrom 2009).
84
85 PAs are vulnerable to political change (Agrawal 2005, Clement 2010), economic fluctuations,
86 and ecological change. Understanding what makes PAs resilient to both ecological and
87 socioeconomic change is therefore important for conservation. We view resilience as being
88 comprised of (1) the ability of a system to remain within the same regime (system state
89 characterized by key processes) following a perturbation; and (2) the capacity of a system to
90 adapt to change and persist through times of change (Carpenter et al. 2001, Lundy and
91 Montgomery 2010). Resilience may also be viewed as the maintenance by a system of a
92 continuous identity in space and time (Cumming and Collier 2005). Resilience itself is not a
93 normative concept, and the resilience of some social-ecological states (e.g., poverty traps) may

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94 be negative from a conservation perspective; we focus here on 'positive' resilience, in the sense
95 of resilience that helps PAs to achieve conservation goals. PAs must change and adapt to
96 changing environmental conditions through time (Lee and Jetz 2008), while seeking to maintain
97 their cultural and social roles as important elements of their identity. The core of their identity,
98 however, lies in the fact that they support, or at least are intended to support, the long-term
99 persistence of populations, species and communities of a wide range of organisms, as well as
100 related abiotic ecosystem elements and processes (Jax 2010) and ecosystem services. If PAs are
101 to be resilient in social, economic and ecological terms, their physical location and boundaries,
102 as well as their management and governance, must be politically viable well into the future
103 (Folke et al. 1996, Adger et al. 2005) lest they become 'paper parks', are made smaller (e.g., the
104 extent of Etosha National Park, in Namibia, is currently about a quarter of what it was in 1907),
105 or are de-gazetted altogether. Management of decision-making processes is therefore at least as
106 important for PA resilience as management of the biophysical system, suggesting that
107 conservation science is necessarily interdisciplinary (Mathevet and Mauchamp 2005).
108 Furthermore, PAs influence the regions in which they are embedded, and are in turn influenced
109 by the broader context of those regions. Clearly, the maintenance and possibly enhancement of
110 PA resilience – in a social-ecological context – is a key goal for conservation biology.
111

112 The social-ecological nature of PAs has already received considerable recognition within both
113 the peer-reviewed literature and cutting-edge conservation practice (Berkes et al. 2003, Fischer et
114 al. 2009, Strickland-Munro et al. 2010, Ban et al. 2013). Despite the existence of a solid body of
115 inter- and trans-disciplinary work on PAs, however, many gaps remain. Here we focus on three
116 particular areas that require further development: (1) the relationships between a social-

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117 ecological perspective on PAs and research from other fields on social-ecological systems and
118 their resilience; (2) scale and the analysis of cross-scale influences and feedbacks on PAs; and
119 (3) assessment of the resilience of PAs. Although many scholars have also argued for greater
120 attention to issues of power in studies of environmental governance (Blaikie 2006, Jentoft 2007,
121 Clement and Amezaga 2013), we do not explicitly focus on this topic in this paper. Nonetheless
122 the close relationship between power and the rules, norms and conventions (i.e., institutions) of
123 human societies means that power is rarely far removed from the discussion.
124

125 PAS AND SOCIAL-ECOLOGICAL SYSTEMS FRAMEWORKS

126 The study of social-ecological systems (SESs) has led to a wide range of frameworks, theories
127 and models that aim to structure inquiry and explain or predict the dynamic outputs of complex
128 adaptive systems. We use 'system' to refer to a cohesive, temporally continuous entity that
129 consists of key elements, interactions, and a local environment (Cumming and Collier 2005).
130 SESs are systems that include social, economic and ecological elements as well as the
131 interactions between them. The concept of an SES is useful for PA management because it
132 explicitly implies that the manager, other stakeholders, and related institutions are part of a
133 cohesive whole, the system. This in turn suggests that approaches that incorporate these
134 elements into dynamic models of system interactions - rather than treating them as immutable
135 external influences on ecosystems - may identify opportunities to enhance the resilience of
136 systems that would otherwise be overlooked. Moreover, PAs do not exist in a vacuum and
137 interact with, contain, and/or are nested within other SESs.

138 Frameworks are underlying sets of ideas that serve to connect and make sense of different
139 concepts (Pickett et al. 2007). They are used to aid the investigation of complex phenomena by

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140 identifying, organizing and simplifying relevant factors, and are generally compatible with
141 multiple theories and models (Pickett et al. 2007, Schlager 2007, McGinnis 2011). Frameworks
142 that have been explicitly developed for understanding social-ecological systems include,
143 amongst many others, resilience (Holling 1973, Resilience Alliance 2007a, b), robustness
144 (Anderies et al. 2004), vulnerability (Turner et al. 2003, Adger 2006), Self-organized Holarchic
145 Open systems (SOHO) (Kay and Boyle 2008, Waltner-Toews et al. 2008), and sustainability
146 science (Kates et al. 2001). All of these approaches have the potential to provide a unified
147 approach for the study of SESs across multiple methods and disciplines (Ostrom 2007, 2009,
148 Poteete et al. 2010); and all are potentially relevant as a platform to better understand the
149 dynamics of PAs. Different frameworks have, however, tended to focus on different elements of
150 the same problem, and no single existing framework can be considered fully comprehensive
151 (Cumming 2011 pp. 37-40). In the context of PAs there is a strong need to bring key ideas from
152 different frameworks together into a more comprehensive body of theory.
153
154 We propose an approach that combines elements of resilience analysis (e.g., Holling 1973,
155 Resilience Alliance 2007b) and the closely related SES framework of Ostrom (2007, 2009),
156 while extending them in several directions. Before we consider how these frameworks can be
157 applied to PAs, a brief summary of each set of ideas and their main strengths and weaknesses is
158 necessary.
159
160 The Resilience Alliance workbooks (Resilience Alliance 2007a, b, 2010) attempt to
161 operationalize key resilience concepts by posing a series of questions to strategically define and
162 assess SESs. Within this broader framework, a nested framework (adapted from Chapin et al.

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163 (2006)) offers a protocol to structure interacting, cross-scale social-ecological components,
164 processes, institutions, and feedbacks. The workbooks use the adaptive cycle and panarchy
165 models (Kenward et al. 2001, Gunderson and Holling 2002), and the adaptive governance and
166 social-network literatures, to facilitate an understanding of system dynamics and interactions,
167 assess governance and offer insights about potential actions. What they lack in a unified
168 underpinning theory (Cumming 2011) is compensated for by their firm grounding in a rich
169 empirical literature spanning many case-studies and multiple disciplines (reviewed in Haider et
170 al. (2012)). In providing a practical way to structure multiple resilience perspectives in complex,
171 dynamic SESs, the framework offers an approach to understand issues of scale in SESs,
172 including PAs, and proposes a novel approach to natural resource management (Walker et al.
173 2009, Strickland-Munro et al. 2010, Haider et al. 2012).
174
175 The resilience approach has, however, been criticized for being difficult to operationalize
176 (Strickland-Munro et al. 2010, Cumming 2011, Holt et al. 2012). Practical problems in applying
177 resilience thinking have resulted in a relatively low number of directly comparable case-study
178 examples. Practitioners have also lamented its lack of guidance for delineating system
179 boundaries, developing tools to navigate a transition to desirable futures, and describing
180 governance structures (Strickland-Munro et al. 2010, Haider et al. 2012, Holt et al. 2012). These
181 criticisms are particularly relevant for PAs, where implicit geographic or ecologically-relevant
182 boundaries (e.g., catchment edges) may not line up with PA boundaries (Mitchell 2011), and
183 where identifying social thresholds and variables, articulating governance choices and
184 incorporating relations of power (Strickland-Munro et al. 2010, Armitage et al. 2012) may be
185 particularly important in defining elements that may contribute to or erode a system's resilience

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186 (Walker et al. 2009).

187

188 Ostrom's SES framework (Figure 1) provides a useful complement to resilience approaches. It
189 has its origins in institutional studies of the commons that made significant contributions towards
190 a game theoretic understanding of environmental governance (Ostrom 1990, Ostrom et al. 1994).
191 It provides researchers an analytical tool with which to capture, organize and analyze a diverse
192 set of social and ecological variables that are considered relevant for a particular aspect of a
193 system (Ostrom 2007, Poteete et al. 2009). In total, Ostrom's SES framework includes over fifty
194 potentially influential classes of variables that are ordered within a multilevel classificatory
195 system. The four core components (resource systems, resource units, actors and governance
196 systems) are organized as a partially decomposable system (Simon 1991) where each of the
197 potentially influential variables can be further unpacked to capture subclasses and cumulatively
198 integrate knowledge concerning their effects on sustainability. There are two additional
199 components that allow for linkages across levels of governance, or between systems, and an
200 additional two components that are used to evaluate SES interactions and outcomes.

201

202 FIGURE 1 HERE

203

204 Ostrom's SES framework has been criticized on several fronts that generally point to two main
205 issues. First, its origin in institutional analysis neglects alternative social scientific perspectives.
206 Most notable among these omissions are the power-laden theories of political ecology that view
207 environmental degradation as a direct consequence of imbalances of power between influential
208 policymakers (e.g., national governments) and their associates (e.g., local elites and businesses)

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209 and marginalized small-scale users (e.g., subsistence farmers and pastoralists) (Peet and Watts
210 1993, Robbins 2004). Second, the ecological aspects of the framework and their interactions
211 remain underdeveloped (Berkes and Ross 2013). A particularly problematic issue for ecologists
212 seeking to apply Ostrom's SES framework is its lack of clear definitions concerning resource
213 units and resource systems. For example, resource units have been operationalized at multiple
214 levels of biological organization, including species and communities (Gutierrez et al. 2011),
215 water and land (Ostrom 2011) and even landscapes for tourism (Blanco 2011). While it could be
216 argued that each of these studies presents an internally consistent application of the framework, it
217 is unclear whether syntheses between such disparate case studies are feasible or if the findings
218 necessarily apply to the broader population of SESs. Third, while dynamic and multi-scale
219 analysis is technically possible, nearly all applications of the framework and its institutional
220 analysis precursor focus on a single focal action situation (e.g., resolution of a natural resource
221 management problem by multiple stakeholders) that occurs once only and in a single location
222 (McGinnis 2011). Moreover, until recent modifications to the SES framework were introduced
223 by Epstein et al. (2013), the framework was poorly equipped to analyze biophysical processes
224 and diagnose ecological contributions to social-ecological outcomes. However, even with these
225 changes, Epstein et al.'s (2013) analysis of the successful remediation of Lake Washington
226 simply transforms inherently dynamic internal phosphorus loading processes into several static
227 one-way relationships with the dependent variable. Although sufficient for their analysis, the
228 failure to account for dynamic linkages within and across scales remains a major weakness of the
229 SES framework. In fact most applications of the framework have a general tendency to focus on
230 a single scale or level of governance, on a single resource, and to treat the problem as if all
231 resources and actors were at the same focal scale.

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233 As analytical approaches for understanding (and hence, better managing) PAs, both resilience
234 approaches and Ostrom's SES framework have much to recommend them. Our objective in this
235 article is to extend them to better integrate social-ecological feedbacks and cross-scale effects
236 that often dominate the dynamics of PAs and other social-ecological systems.

237

238 EXTENDING EXISTING FRAMEWORKS TO INCLUDE SCALE AND CROSS-SCALE FEEDBACKS

239 The obvious tension between ecological and social demands in many PAs suggests that analysis
240 of the resilience of PAs requires a hierarchical, cross-scale and multi-level framework in which
241 different scales and institutional levels are connected by a set of interactions between different
242 actors, resources and processes. Examples of interactions include the movements of actors and
243 resources (e.g., tourism, water flows out of PAs to downstream communities) as well as the
244 interplay of rules and information across scales. Holling (2001) suggested that complex system
245 behaviours, such as those that we observe in PAs, arise from the interactions of processes that
246 occur at a minimum of three different spatial and temporal extents; and furthermore, that in many
247 cases, shifts between different system states are driven by changes in the slower variables (e.g.,
248 buildup of Phosphorus in a shallow lake, or loss of trust in human society) rather than the faster
249 variables (e.g., trophic interactions or law enforcement).

250

251 It is important to recognize that PAs, which are institutions (in Ostrom's sense) rather than
252 biophysical entities, have been created at a variety of different spatial scales and institutional
253 levels. While PAs in the IUCN categories I-IV are often single tenure units, those in categories V
254 and VI (such as Biosphere reserves and Transfrontier conservation areas) usually include

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255 multiple, nested tenure units that are governed by different rules. For example, the current rules-
256 in-use in the Greater Limpopo Transfrontier Conservation Area or the Causse Méjan (both of
257 which are discussed in more detail later in this paper) differ between farms, core conservation
258 areas, hunting areas, and designated buffer zones. Similarly, while larger areas may be expected
259 to change more slowly because of the buffering effect of larger ecological populations, this is not
260 inevitable; political change that has an influence at a national extent, for example, can happen
261 swiftly. In heterogeneous landscapes, different tenure units at the same spatial scale may also
262 interact (e.g., mines and conservation areas).
263
264 We propose a system description that includes five hierarchical levels of institutional
265 organization. These in turn are related to five hierarchical spatial scales of analysis, with some
266 flexibility, depending on the system that is under analysis (Figure 2). The first institutional level
267 is defined as the *sub-tenure unit*. It refers to patches of habitat (or any other fine-scale, discrete
268 ecological units that are managed differently), and/or specific human use areas, that (1) fall
269 within a single tenure unit; (2) have a single management policy; and (3) exist at smaller spatial
270 extents than the boundaries of the tenure unit. For example, different rules about making fires or
271 leaving your vehicle may apply at picnic sites or bird hides (blinds) within a PA; and different
272 habitats in a PA may have different management needs. Sub-tenure units will always, by
273 definition, have a smaller spatial extent than a PA. They relate most closely to the *patch scale* of
274 analysis, which reflects the grain and extent of habitat heterogeneity within the PA.
275
276 The second institutional level is that of a *single tenure unit*. Single tenure units belong to a single
277 owner or organization. They may have the same extent or a smaller extent than that of a PA,

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278 depending on the diversity of tenure types and human use zones occurring within the PA. Single
279 tenure units define one or several scales of analysis that might (for example) correspond to the
280 extent of a traditional game park, or to those of core ecological and farming areas respectively
281 within a Biosphere reserve.
282
283 The third institutional level, the *proximate institutional context*, includes multiple tenure units as
284 well as the institutions and organizations that are responsible for coordinating the interactions
285 (where these occur) between tenure units. Depending on the nature of the study system, the
286 proximate context might define a spatial scale that is only slightly larger than the PA, or a larger
287 region that contains a network of PAs that are managed with a shared objective. For example,
288 provincial parks in the Western Cape of South Africa form a network that is overseen by a
289 regional conservation organization, Cape Nature; the proximate institutional context for any
290 single provincial park includes Cape Nature, and related ecological scales of analysis include
291 surrounding PAs and unprotected dispersal corridors that connect PAs. The proximate
292 institutional context also includes institutions that relate to the governance of resources around
293 PAs, particularly where (as in the case of water laws, for example) they relate directly to
294 ecological flows (e.g., water, invasive species) that might enter the PA from surrounding areas.
295
296 Proximate institutions in turn sit within (or sometimes straddle) a *national institutional context*,
297 the fourth level, which typically consists of the institutions of a single nation-state (e.g., its
298 constitution and related governance structures). This institutional level aligns with a national
299 extent of analysis. However, sometimes, as in the case of transboundary conservation areas, PAs
300 may include as many as three or four nations, creating an *international institutional context* that

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301 is the fifth and final institutional level. This fifth level includes international power relations and
302 the global economy. International contexts are aligned with the broadest scales of spatial
303 analysis, ranging from multiple countries to global. While the fifth level may seem ecologically
304 far removed from the majority of established PAs, it has particular relevance for migratory
305 species and related resources, such as wetlands that are important for migratory waterbirds and
306 are supposedly covered by international conventions and agreements (e.g., CBD, Ramsar,
307 AEWA; see United Nations 1992, Matthews 1993, Lenten 2001). Similarly, international
308 conventions and agreements (or lack thereof) can have a strong influence at the level of a single
309 tenure unit, as in the case of the management of species that are listed in Appendix I of the
310 Convention in Trade and Endangered Species (CITES).
311
312 At each different scale and level, different temporal dynamics occur. The temporal scales that are
313 relevant to the ecology of PAs range from short term processes such as predation and
314 competition that occur on a daily scale, through seasonal processes such as breeding or wintering
315 seasons for birds, to long-term processes such as atmospheric oscillations, ocean acidification,
316 and climate change that take place at decadal and centennial scales. Similarly, the temporal
317 scales within the social realm also vary from short-term initiatives to establish PAs to long-
318 standing national assets such as Yellowstone National Park in the USA. Social history and pre-
319 PA politics may also affect the resilience and social-ecological context of a PA. Both ecological
320 and social processes act synergistically to produce outcomes and thus neither can be considered
321 in isolation (Hughes et al. 2005).
322
323 FIGURE 2 HERE

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324

325 The boundaries of a PA can span multiple nested institutional and ecological levels and scales.
326 Each PA interacts directly with its immediate context (i.e., defined by the scale and level above),
327 which becomes the main source of both inputs and outputs (e.g., information, finances) for any
328 given PA. Since the number and diversity of people involved in SESs at different levels affects
329 both ecological and social processes and the temporal periods over which they occur (Westley et
330 al. 2002), it is crucial to take these interactions into consideration. Practitioners often speak of
331 getting the different levels of governance aligned: for example, a decision made internationally,
332 at say Ramsar Convention level, may or may not promote wetland sustainability, depending on
333 whether the national government/s that are involved take action and are supported by local
334 communities. In other cases, local communities may seek support at the international level for
335 initiatives that lacked support from their own national governments. Alternatively, some of the
336 policies funded and promoted by international donors and organizations may contribute to
337 systematic disenfranchisement of local communities despite a supporting rhetoric of social
338 justice (Blaikie 2006). Positive synergies among scale-dependent institutions therefore usually
339 depend upon brokering organizations that facilitate (even make possible) the interactions
340 between the various levels, including in the reverse direction so that the national governments
341 and Ramsar convention receive the necessary confirmation or other feedback to assist future
342 policy formulation. Worldviews, values, attitudes, and power are key factors that shape PA
343 design and governance and shape the behaviors and practices of social groups operating at
344 different spatial levels that directly or indirectly affect PAs.

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346 Resources and biophysical processes exist over a range of different scales, and vary in their grain
347 (or frequency) and their extent (or duration) in space and in time. The scale of socioeconomic
348 processes depends heavily on the scale of economic and political organization and the level of
349 international interest in a particular PA (Figure 3). It ranges from individuals to networks of
350 organizations and includes the effective scales of social institutions (rules, laws, policies, and
351 norms) that govern the extent of resource-related rights and management responsibilities
352 (Cumming et al. 2006). For example, in creating an urban PA, a country's constitution may
353 provide for national-level tenure rights that must then be applied within the local context of
354 municipal policies and by-laws. Scale-dependent system components and interactions may
355 influence PAs in different ways depending on how their relative magnitude and frequency
356 change across different scales. It is often unclear where resilience, or a lack of resilience, resides
357 – both within and between scales. The interactions between different spatial and temporal scales
358 of both pattern and process, and their potential effects on resilience, are recurring themes in the
359 ecological literature (e.g., Peterson et al. 1998, Cumming et al. 2006).
360
361 FIGURE 3 HERE
362
363 Dealing with the many scale dependencies of PAs is conceptually challenging. However, as Cash
364 et al. (2006) point out, ignorance of cross-scale interactions tends to reveal itself in a wide range
365 of management problems. Therefore, a useful starting point is to be explicit about the spatial and
366 temporal elements of the problem and their key scales (Figure 4). PAs in contemporary
367 conservation efforts are developed as networks (Vimal et al. 2012). They are planned and
368 increasingly managed as part of local, regional and international conservation systems. For

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369 example, in the French national park and biosphere reserve design approach, new PAs are
370 designed as a set of zones that range from strictly protected areas (core area of national park or
371 nature reserve) to integrated zones in surrounding areas where integrated management of natural
372 resources is implemented with local stakeholders and landowners (Batisse 1997, Mathevet et al.
373 2010).
374
375 Social-ecological interactions occur most intensively within and between entities that operate at
376 similar scales (Allen and Starr 1982, Levin 1992, 1999) (Figure 2). For example, in South
377 Africa, provincial administrations such as Cape Nature or Ezemvelo-KZN Parks manage
378 provincial parks, while national parks are regulated nationally by SANParks. At the same time,
379 actors and processes at scales and levels above and below the focal scale influence pattern-
380 process interactions via flows between nested elements. Matter includes the exchange of physical
381 materials across scales and levels, such as water, carbon, and nitrogen. Organisms, including
382 people as well as mobile animals and plant propagules, link scales and levels via their
383 movements (e.g., labour, migration, transhumance). Information flows include the exchange of
384 ideas, perceptions and skills across scales. These local to global flows and the ways in which
385 they are mediated and managed can play an important role in the function and performance of
386 the PA (Mathevet et al. 2010, Thompson et al. 2011) and may consolidate ecological and social
387 interdependence in biodiversity policy that goes beyond park boundaries, such as the health of
388 the tourism sector in and around PAs (Hall 2010, Biggs 2011). Rules link institutions and
389 regulations across scales, for example with global treaties affecting regulations within PAs. In
390 addition, flows of information, perceptions, and money across scales are central to the
391 functioning of the nature-based tourism sector in many of the world's PAs (e.g., Biggs 2011).
392

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393 The presence of different interlinked subsystems across different scales (Figure 4) suggests the
394 presence of multiple action arenas where decisions related to PAs are made and a strong need to
395 somehow align multiple subsystems to coordinate responses to common threats (e.g., climate
396 change or an escalation of poaching activity). This observation aligns neatly with Holling's ideas
397 about panarchies (Holling and Gunderson 2002), which suggest that some degree of synchrony
398 in system cycles is a necessary pre-condition for effective interventions (Westley et al. 2002).
399
400 The adoption of a multi-scale, social-ecological perspective on the resilience of PAs (Figures 2-
401 4) provides a useful way of organizing and thinking through their long-term sustainability. Over
402 the last decade, conservation organizations have increasingly recognized that the protection of
403 ecosystems requires that key ecosystem functions and processes be maintained at multiple scales
404 (Poiani et al. 2000). Several of the world's largest conservation NGOs have developed stratified,
405 ecoregional-based plans and approaches to formally structure the process of developing and
406 maintaining PA networks (e.g., TNC 2003, Loucks et al. 2004). Poiani et al. (2000), for instance,
407 developed a hierarchical classification for habitats (ranging from small patches through the
408 matrix to entire regions) and associated species (ranging from small patch species through to
409 regional and long-distance migratory species; Figure 4) as part of TNC's 'Conservation by
410 Design' initiative.
411
412 FIGURE 4 HERE
413
414 We propose that a similar leap forward must be taken by recognizing that multi-scale
415 socioeconomic (and further, social-ecological) 'functional landscapes' exist, and that they are

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416 integral to understanding and managing PAs for long-term sustainability. For example, the Man
417 and the Biosphere Programme (UNESCO) integrates social and ecological goals and aims to
418 ensure the sustainable use of natural resources, while also emphasizing the interdependencies of
419 cultural and natural landscapes (Batisse 1971, IUCN 1979, Batisse 1997, German MAB National
420 Committee 2005). Such areas are structured and organized at a range of social and ecological
421 scales, depending on the particular set of negotiated goals and objectives. The new concept of
422 ecological solidarity, a core feature of the 2006 law reforming national park policy in France,
423 similarly stresses the need to reconnect people to their PAs. Ecological solidarity is both social
424 and ecological; it is based on social recognition of the spatial interdependence among natural
425 organisms, including people, and their physical environment. This sets the scene for a vision of
426 nature conservation and management of PAs. Ecological solidarity offers a pragmatic
427 compromise between ecocentric and anthropocentric ethics. It suggests that biodiversity
428 conservation at different spatial and temporal scales needs to be collectively explored by local
429 communities and stakeholders to give social meaning to the establishment of PAs, to the
430 expansion of ecological networks, and to the integrated management of cultural landscapes
431 (Mathevet 2012).
432
433 As an example, conservation of a 'local-scale species', such as an endemic butterfly, typically
434 requires fewer resources and a much finer scale of management than that which is required to
435 conserve species that use their landscape at a regional scale (e.g., migratory songbirds). In the
436 same way, meeting local stakeholder needs and demands within and around a PA requires
437 different and much finer-scale action than governmental resource policies, the international
438 tourist market, or the international trade in animal products. These ideas can be summarized by

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439 uniting the ecological approach of Poiani et al. (2000) with a socioeconomic perspective (Figure
440 5).
441
442 FIGURE 5 HERE
443
444 Figure 5 provides a way of conceptualizing and comparing the different scales and levels at
445 which social and ecological systems are organized. It does not, however, provide a dynamic
446 temporal perspective for understanding interactions between scales. One of the key components
447 of incorporating scale and scaling in a framework for the analysis of PA resilience is that of
448 understanding feedbacks, both within and between scales. Formally, a cross-scale feedback
449 occurs if (1) A influences B and B influences A; and (2) A and B are system elements (whether
450 human or not, but excluding interactions) that exist at different scales. For instance, global
451 demand drives the prices of many commodities but production is often limited to a smaller sub-
452 set of locations. If local conditions in the production location influence global prices, a local to
453 global interaction occurs. If global prices also influence local actions, a cross-scale feedback
454 occurs. Such feedbacks may be extremely difficult to manage given the inherent complexity of
455 social-ecological systems (Berkes et al. 2006). For example, the Asian demand for rhinoceros
456 horn is driven by cultural beliefs. Coupled with limits on local production (i.e., a small number
457 of slowly-reproducing rhinos), it has created spiraling commodity price increases and a massive
458 conservation problem for African PAs (Biggs et al. 2013). Our future ability to manage
459 individual resources, or PAs as a whole, will depend on our ability to devise a system that can
460 detect potentially harmful feedbacks and respond to them in a timely manner (Hughes et al.
461 2005, Biggs et al. 2013).

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462

463 The different social-ecological system elements that determine the resilience of an individual PA
464 may be connected in different ways and to varying degrees of strength (Figures 2-4). One of the
465 challenges in analyzing PA resilience is to determine which influences are the strongest within
466 the system and which are sufficiently weak that they can safely be ignored or disregarded during
467 analysis (keeping in mind that sometimes, weak influences and dormant social networks can be
468 important in times of crisis). Closed feedback loops (A influences B influences C influences A)
469 are also of particular importance because they can produce surprising dynamics, such as
470 dampening or exacerbation of local variability. In practice these feedbacks (and especially those
471 that reinforce one another) are critical for system performance and must be considered in the
472 design of environmental policies as they are directly responsible for the stability of a social-
473 ecological system in a given state. Conversely, if system change is desired, they must in some
474 direct or indirect manner (e.g., through modifying other inter-linkages which feed into it but can
475 be influenced) be overcome. For example, in the Eastern Cape case study discussed below and in
476 Maciejewski & Kerley (in press), managers' perceptions of what tourists want to see provide a
477 powerful driver for the ecological management of private PAs (PPAs). This influence is cross-
478 scale in the sense that tourists come from a far wider extent than the PA. By their actions,
479 managers in turn influence the likelihood that tourists will visit the PA, setting up a cross-scale
480 feedback that can result in harmful ecological effects (e.g., habitat alteration by excessive
481 numbers of elephants, and resulting species loss) within PA boundaries. Breaking this feedback
482 requires that managers be willing to accept data indicating that tourist numbers would be
483 unaffected by lower stocking rates, and willing to take the risk of reducing population levels of
484 charismatic megafauna such as elephants.

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485

486 While many studies have implied or discussed the importance of scaling principles and cross-
487 scale dynamics for PAs, few have explicitly analyzed them. Some exceptions include Jones et al.
488 (2013) and Mills et al. (2010) (both on MPAs) and Guerrero et al. (2013). Guerrero et al. (2013)
489 identified eight ways in which scale mismatches between actors and resources involved in the
490 spatial planning process manifest themselves. These include (1) ecosystem or ecological
491 processes that extend beyond governance boundaries; (2) the absence of resolution-appropriate
492 data for decision making; (3) a lack of implementation capacity; (4) threats to ecological
493 diversity that operate at diverse spatial and temporal scales; (5) mismatches between funding and
494 the long-term nature of ecological processes; (6) rates of implementation that do not reflect the
495 rate of change of the ecological system; (7) lack of appropriate indicators for monitoring
496 activities; and (8) the occurrence of ecological change at scales smaller or larger than the scale of
497 implementation of management actions or monitoring.

498

499 Among the most important questions in this context are (1) whether, and how, PAs may
500 contribute to desirable regional resilience (e.g., Plumptre et al. 2007, Slotow and Hunter. 2009,
501 Cantú-Salazar and Gaston. 2010, Laurance 2013, Sjöstedt 2013); and conversely, (2) how
502 regional resilience may influence the resilience of individual PAs (González et al. 2008, Jones et
503 al. 2013).

504

505 UNDERSTANDING THE RESILIENCE OF PROTECTED AREAS

506 In the preceding sections we have argued that (1) PAs are multi-scale and multi-level social-
507 ecological systems; and (2) an explicit recognition of scale and cross-scale interactions must be

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508 incorporated in analyses of PA resilience if we are to advance our understanding of their
509 dynamics, manage them better, and ultimately foster their resilience. The third logical step in this
510 line of argument is to consider empirical evidence that indicates whether, and how, cross-scale
511 feedbacks may in practice influence the resilience of specific PAs, and how PAs may in turn
512 influence regional resilience. The starting point is to define different scales and levels; this is
513 followed by a more detailed consideration of system dynamics. We illustrate these steps below
514 for three real-world examples, noting that space constraints and the goals of this article do not
515 permit the next step, which would be a full resilience analysis of each case. As the subsequent
516 discussion shows, the nature of the interaction between regional and local resilience may be quite
517 strongly dependent on context-specific factors.
518

519 *Case Study 1: Social-ecological dynamics of Private Protected Areas in the Eastern Cape*

520 Private Protected Areas (PPAs) constitute a high proportion of conservation land in South Africa.
521 Exact figures are hard to obtain, but according to the PAs Act 57 of 2003, approximately 7% of
522 the country's land is in statutory national parks and 17% in some form of private conservation
523 area (Cousins et al. 2008). In southern Africa, ecotourism generates roughly the same revenue as
524 farming, forestry and fisheries combined (Scholes and Biggs 2004). Growth in the ecotourism
525 industry has had substantial impacts in the Eastern Cape, where large areas of marginal pastoral
526 lands have given way to PPAs. Private PAs may fall within any of the IUCN categories. Some
527 believe they are better represented under categories IV – VI, although many private PAs fit the
528 management objectives of categories I – III (Dudley 2008).
529

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530 At the **sub-tenure level and patch extent,** within PAs, former agricultural fields with
531 interspersed natural areas have been converted into more economically viable game farms. This
532 involves restoring the vegetation and reintroducing wildlife into the area. At the **PA level,** system
533 dynamics and related ecological management decisions are heavily driven by economic
534 processes. Private PAs aim to build populations of charismatic species at stocking levels that
535 ensure tourist satisfaction. It has been estimated that during the establishment of PPAs, the
536 introduction of species to the Eastern Cape cost between $97,500 and $1.8 million (Sims-Castley
537 et al. 2005). Stocked animals are often extralimital species, such as giraffe, which did not
538 historically occur in the Eastern Cape. These non-indigenous introductions have several negative
539 effects including hybridization, degradation of habitat, and low survival rates and competitive
540 exclusion of indigenous species (Chapin et al. 2000, Castley et al. 2001). Stocking charismatic
541 species, such as the African elephant (*Loxodonta africana*), above ecological carrying capacity to
542 meet social demands and ensure tourist satisfaction may also have negative ecological impacts.
543 Numerous studies have documented significant impacts of elephants on biodiversity (e.g.,
544 Cumming et al. 1997, Blignaut et al. 2008, Kerley et al. 2008).
545

546 At **regional, national, and international levels and extents**, the main driving forces are social-
547 ecological processes, represented by two conflicting trends. On one hand the land conversion
548 trend increases ecotourism in the Eastern Cape, potentially leading to an increase in income and
549 job opportunities, and resulting in social uplift and poverty alleviation in the rural communities
550 surrounding the PPAs. On the other hand, the ecological carrying capacity of the PPAs places a
551 threshold on the types and numbers of species that can be introduced. The habitat fragmentation
552 and land degradation that can result from overstocking large herbivores may reduce the number

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553 of national and international tourists visiting the area. In addition, as a consequence of South
554 Africa's history, many areas of the Eastern Cape are contested (Cundill et al. 2005); reserve
555 creation may engender social resentment and create political opposition to conservation,
556 particularly if it entails the loss of jobs formerly provided by agriculture (Brooks et al. 2011).
557

558 *Case Study 2: Man and the Biosphere (MAB) case: Regime shifts on the Causse Méjan*

559 The Causse Méjan is a limestone plateau (1000m average altitude) in the Cévennes Mountains of
560 France. It is home to the largest steppe-like grassland in France (Fonderflick et al. 2013), and is
561 part of the core area of the Cévennes National Park (372000 ha) and the Cévennes Biosphere
562 Reserve. Both PAs were created to maintain a rural way of life (including sheep and cattle
563 farming, and cheese production) as well as to support the conservation of indigenous grassland
564 and several endangered species (e.g., vultures, Przewalski's horse). The Causse Méjan is an
565 IUCN category VI PA. Farmers are the managers of open meadows and steppes, which cover
566 37% of the core area; the rest is forest (O'Rourke 1999, Etienne and Le Page 2002). The plateau
567 is ecologically vulnerable to bush encroachment and invasion by pine, boxwood and juniper trees
568 (Etienne 2001).
569

570 At the **patch scale**, the main ecological driving force is the pine seed rain intensity. There is a
571 threshold of grazing pressure above which pine encroachment is impossible. Below this
572 threshold, pine tree regeneration can be controlled by mechanical or manual removal of pine
573 seedlings. The transformation of grassland to woodland represents a local ecological regime
574 shift, but may not be a regime shift at the extent of an individual farm because the main driving
575 forces at the **sub-tenure level** are economic. Here, social-ecological regime shifts are provoked

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576 by changes in the percentage of a farm covered by pine forest but the threshold will differ
577 according to the area of grassland per stock required by the farming system (Kinzig et al. 2006).
578 The farmer will select which farming system to practice for cultural and economic reasons that
579 are largely derived from higher levels, such as national prices for livestock (Etienne and Le Page
580 2002). Both vegetation patches and farms occur within the broader extent of the biosphere
581 reserve.
582
583 At the biosphere reserve (**PA and PA network levels)** and the **regional extent**, the main driving
584 forces are both social and ecological, potentially producing two conflicting kinds of system
585 change. On one hand, a regime shift may occur between cheese and timber production,
586 depending on the unstable interactions between Roquefort cheese, Fedou cheese (a local cheese
587 that like Roquefort, is produced from sheep's milk) and lamb meat producers, and timber
588 producers (O'Rourke 1999, Kinzig et al. 2006). On the other hand, the pine-grassland dynamic
589 may result in ecological regime shifts and the loss of open grassland biodiversity (Kinzig et al.
590 2006). Finally, **national level** institutions, policies and **international** commodity demands will
591 influence economic tradeoffs in this system.
592
593 Interestingly, two recent changes have provoked a new regime shift and management paradigm.
594 First, in June 2011, the Causse Méjan and some neighboring sites of the Cévennes, were declared
595 as world cultural heritage sites by UNESCO for their agro-pastoral Mediterranean landscape.
596 Second in the summer of 2012, and for the first time in the 21st Century, wolf attacks were
597 registered (n=36) and 22 ewes killed. The Causse Méjan social-ecological system is now at a
598 threshold. Will it switch to a bushy and abandoned farmland landscape, supporting the

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599 establishment of a permanent wolf pack, or will it remain an agropastoral landscape, giving
600 priority to sustainable sheep grazing practices and the conservation of open grassland? This
601 dilemma questions the goals and practices of the national park, especially in its core area, as well
602 as the adaptive capacity of farmers to integrate predators into their grazing system.
603

604 *Case study 3: The Greater Limpopo Transfrontier Conservation Area*

605 The Greater Limpopo Transfrontier Conservation Area (GLTFCA, c. 90,000 km^2) includes
606 adjacent parts of Mozambique, South Africa and Zimbabwe. The core PA comprises three
607 national parks (IUCN Category II): Limpopo in Mozambique, Kruger in South Africa, and
608 Gonarezhou in Zimbabwe. Other PAs, mostly IUCN Category VI, are included in each country,
609 as are areas of communal and private land. State PAs cover 53% and communal lands 34% of the
610 area, respectively (Cumming et al. 2013). The core GLTFCA, created by treaty between the
611 three countries, is embedded within a provisional transfrontier conservation area that may serve
612 as a buffer that increases the resilience of the GLTFCA. Within South Africa, the Kruger to
613 Canyons Biosphere initiative (Coetzee et al. 2012) is extending the area under protection (IUCN
614 Category VI).
615

616 Historically, Khoisan people occupied the area for millennia before Bantu agro-pastoralists
617 arrived some 2,000 years ago. Livestock appeared in areas adjacent to and within the GLTFCA
618 between 600 and 1200 AD and various species of antelope, and hippo and elephant were hunted
619 and ivory was traded at the coast (Plug 2000). The period 1200 - 1800 was characterised by
620 shifting tribal control of the region and Nguni invasions.
621

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622 The entry of smallpox and measles into the region in the 1830s and the rinderpest pandemic in
623 1895 took their toll on both humans and ungulates respectively. The major transitions and drivers
624 and associated social-ecological changes in the GLTFCA landscape are summarised in Fig. 6.
625 At the **patch scale and sub-tenure unit level**, within the GLTFCA, changes have occurred in
626 ecological habitat connectivity, disturbance regimes, water availability, and herbivore species
627 composition and abundance as well as in the settlement patterns of people and their farming
628 practices. At the **protected area scale**, numerous changes have occurred in boundaries and
629 associated tenure rights (see detailed explanations in Cumming et al (2007), and Anderson and
630 Cumming (2013)). The key feature of the changes that have occurred since 1830 is that they
631 have largely been driven by political dictates at **international and national levels**. Initial
632 change was driven by European colonisation of the three countries, and then by national policies
633 of racial segregation resulting in the development of dual agricultural systems in South Africa
634 and Zimbabwe. This resulted on the one hand in the development of large commercial farms on
635 privately owned land and on the other, in increased densities of traditional small scale agro-
636 pastoral farms in communal lands. Superimposed on this matrix were the formation of state PAs
637 and the resulting displacement of people.

638

639 The continuing top-down influences of international and national policies and legislation on
640 resource management in the GLTFCA continue, with significant impacts on the management of
641 animal diseases (e.g. Foot and Mouth Disease) and the conservation and management of three
642 species of charismatic mega-herbivores (elephant and black and white rhinoceros) (Biggs et al.
643 2013).

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645 FIGURE 6 HERE

646

647 *Key Elements within Case Studies*

648 Despite the different locations and scales of each of the three case studies, they share

649 considerable commonality in their key drivers (Figure 7).

650

651 FIGURE 7 HERE

652

653 Interestingly, our case studies suggest that ecological processes are often most directly relevant

654 to PAs at intermediate to finer scales. In the Eastern Cape case study, carrying capacity and

655 habitat fragmentation both occur at the patch and PA scales. Similarly, pine seed rain intensity,

656 grazing pressure, bush encroachment, grassland to woodland transformation, predator-prey

657 dynamics and species home-ranges are finer-scale elements in the Causse Méjan. In the

658 GLTFCA, ecological habitat connectivity, disturbance regimes and herbivore species

659 composition and abundance are also patch- and protected-area scale processes and patterns.

660

661 At broader scales, the dominant processes that shape and alter PAs are primarily sociopolitical

662 and economic. In our case-studies, the top-down drivers were elements such as tourism demands

663 (Eastern Cape case study), international policies and commodity demands (Causse Méjan), and

664 colonization and international and national policy changes (GLTFCA).

665

666 Sociopolitical and economic processes may of course impact ecosystems via impacts on the

667 abiotic environment, as in the case of anthropogenic climate change, which is driven by human

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668 socioeconomic demands for such things as energy, transport, and manufactured goods. The main
669 exception to this general pattern arises when migratory species are particularly important
670 elements of a PA; this is not the case in any of our examples, but it is not uncommon. We could
671 also envisage that regional ecological influences become relatively more important for smaller
672 PAs that are more dependent on colonization from nearby natural areas that are not necessarily
673 within the boundaries of the PA (Bengtsson et al. 2003).
674
675 *Dynamic interactions within case studies*
676 If we consider a more dynamic representation of cross-scale interactions, the different variables
677 summarized in Figure 7 interact to drive change in PAs. In Figure 8 we graph the spatial scale of
678 our case-study variables against a notional speed at which these processes typically operate.
679
680 FIGURE 8 HERE
681
682 As these graphical depictions show, temporal scales do not arrange as readily along a hierarchy
683 as spatial scales, creating opportunities for spatial-temporal scale mismatches (Cumming et al.
684 2006).
685
686 Since system changes are usually driven by feedbacks, particularly cross-scale feedbacks
687 (Walker et al. 2006), it follows that slower feedbacks and feedbacks from slower processes will
688 take longer to drive change than feedbacks from faster processes. Our examples show that top-
689 down, broad-scale processes like tourism demand can change over short time periods, while
690 processes like habitat fragmentation manifest at a smaller spatial scale, but can take much longer

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691 to manifest and drive change. If, as our PA examples show, ecological processes such as
692 succession and trophic cascades generally occur at smaller, slower scales (i.e., more gradually
693 and at smaller extents, noting that biophysical perturbations are not 'ecological processes') and
694 socio-economic drivers occur at broader, faster ones, an emerging hypothesis is that because of
695 differential selection, PA social-ecological systems gradually become better adapted to cope with
696 changes that result from sociopolitical drivers than with feedbacks from ecological processes. As
697 a result of inertia and cross-scale gradients, top-down sociopolitical processes may drive the
698 system to develop along a trajectory that renders it less resilient to large shocks that may
699 eventually manifest from cross-scale ecological feedbacks. For example, timber demand during
700 and after the second world war led to forest fire management policies in the USA that were
701 designed to save timber; resulting management approaches eventually led to the hugely
702 destructive 1988 fire in Yellowstone National Park.

703 *Case Study Insights*

704 Figures 7 and 8 provide strong support for two general points that we have emphasized
705 throughout the paper. First, PAs function as social-ecological systems, and hence understanding
706 their social and economic components is as fundamental as understanding their ecology if we are
707 to analyse and manage their resilience. Second, cross-scale processes are highly relevant to the
708 resilience of PAs and should be considered as integral to any analysis, rather than treated as
709 subordinate to analyses of system dynamics at a single scale.

710

711 In addition to current cross-scale influences, the history and current objectives of each case study
712 PA play an important role in their current resilience. In the Causse Méjan, with its long history of
713 human use and livelihood support, the PA is politically uncontested and is seen as a way of

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714 maintaining its unique regional identity. In southern Africa, with its colonial history, PAs are
715 sometimes seen as a form of neo-colonial land grab. This is particularly true in South Africa,
716 where the memory of apartheid is still recent. About 40% of National and Provincial PAs in the
717 Eastern Cape are under some form of land claim from historically dispossessed local
718 communities, and the political acceptability of PPAs is unclear. The potential for land
719 redistribution from conservation to agriculture, whether legally or through illegal occupation (as
720 has occurred in Zimbabwe), therefore represents a very real possibility. PAs in South Africa
721 must maintain their sociopolitical resilience by remaining accessible and continuing to cater for
722 and support all strata of society, even if this reduces their overall potential economic viability.
723 Similarly, although the GLTFCA was created after the end of apartheid, Kruger Park has a
724 contested history and the greater PA was also created in a relatively top-down manner by
725 intergovernmental agreements. Its continued viability as a conservation area thus depends
726 heavily on maintaining its political acceptability.
727
728 It is obvious that PAs and their effectiveness in conserving biodiversity will be influenced by
729 regional changes, particularly in relation to politics, governance, and conflict. Uncertainty over
730 land tenure can definitively undermine conservation efforts. For example, ongoing conflict in the
731 Democratic Republic of the Congo, and the displacement of local communities from their land,
732 is endangering key populations of chimpanzees and gorillas; and poor governance and land
733 appropriations in Zimbabwe have undoubtedly contributed to declines in rhinoceros populations
734 in Zimbabwean PAs. One of the starkest conservation challenges in regions with poor
735 governance remains that of working out how to protect PAs against the winds of political
736 change.

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737

738 Our case studies also suggest that PAs contribute to regional social-ecological dynamics and
739 hence to regional social-ecological resilience. For example, in the Eastern Cape, if PAs maintain
740 patches of indigenous vegetation that would otherwise be converted to agriculture, they may be
741 able to cumulatively reduce local fragmentation and maintain a range of ecosystem services and
742 natural processes (as has been shown in similar systems: e.g., seed dispersal by cavity-nesting
743 birds that depend on dead wood in old, large trees; Joseph et al. (2011)) that contribute positively
744 to human wellbeing (Cumming and Spiesman 2006). Similarly, in the Causse Méjan, the PA
745 contributes to building and maintaining a regional identity that includes an awareness of the
746 reliance of the community on ecosystems.

747

748 ## DISCUSSION

749 We have argued that if we are to understand and enhance the long-term resilience of PAs, we
750 must adopt an inter- or trans-disciplinary perspective that incorporates (at a minimum) elements
751 of ecology and social science. Similarly, our analysis shows that questions of scale and
752 recognition of cross-scale influences are of fundamental importance for PAs. Our case studies
753 illustrate the interlinked nature of PAs as social-ecological systems. Intriguingly, it is particularly
754 at broader scales that social, political, and economic considerations become paramount. While
755 this may be due in part to ways of thinking or management practices that are still rooted in the
756 internationally validated and powerful wilderness discourse, it also reflects the broad-scale
757 nature of socioeconomic processes and ongoing globalization.

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759 Our case study analysis does not explicitly consider an additional element of scale-related
760 problems and multi-scale interactions, that of emergent 'higher-level' system properties arising
761 from the interactions of elements at a single scale. Many PAs belong to socioeconomic networks.
762 These may be formal, as in the case of National and Provincial Parks, which are generally the
763 responsibility of a governmental management agency; or informal, through exchanges of
764 information and resources (e.g., Goss and Cumming 2013). PAs are also members of an
765 ecological network that facilitates the propagation and movements of animals and plants.
766 Membership in a network may increase the resilience of an individual PA (e.g., by providing
767 additional options for problem solving) or decrease it if acts to serve the interests of local,
768 regional and global elites (e.g., if membership in a network demands the imposition of locally
769 inappropriate management practices). Clearly, network membership and its relevance for PA
770 resilience will change with scale and should thus form part of any scaling analysis of PA
771 resilience.
772
773 Although they remain propositions rather than established generalities, our cross-scale extension
774 of Ostrom's SES framework suggests some general theoretical principles for the resilience of
775 PAs. These propositions can serve as the basis for more specific hypotheses that future studies
776 about social-ecological resilience of PAs can test. First, there is a relationship between the scales
777 and levels at which different system elements exist and the frequency and/or magnitude of their
778 interactions. This is a general principle that is derived from hierarchy theory and has been further
779 reinforced by ecological research (Allen and Starr 1982, Levin 1992, 2005). Fine-scale processes
780 may be irrelevant for understanding system dynamics at larger scales of analysis, or conversely
781 may occur at speeds such that larger-scale dynamics are largely irrelevant for their outcomes. For

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782 example, the movements of individual atoms are inconsequential to understanding an animal's
783 movement path; and continental drift has had a profound influence on global species
784 composition but is largely irrelevant for understanding PAs at the time scales that are of interest
785 to managers. It may also be easier to generalize about larger-scale pattern-process dynamics
786 because a considerable amount of fine-scale variation is averaged out at broader scales (Levin
787 1992). Social-ecological feedbacks should therefore be most pronounced when they occur
788 between a given functional scale of the ecosystem and the most closely aligned socioeconomic
789 scale, and/or the scales immediately above or below the focal scale (see Figure 4). For analyses
790 of PA resilience, this means that recognizing and making explicit the ways in which system
791 scales and levels align and interact with one another should clarify the most important
792 perturbations against which resilience and adaptive capacity must be built, and help in making
793 decisions about management tradeoffs. For example, in the GLTFCA, threats to the area's
794 protected status from higher-level political processes may suggest enhancing social acceptability
795 and community engagement through providing greater access to parts of the PA or the resources
796 that it contains (e.g., permitting mopane worm harvesting (Makhado et al. 2009, Gondo et al.
797 2010)), whereas threats from pathogens introduced by or transmitted to livestock in neighbouring
798 areas may require greater segregation and reduced access (Rodwell et al. 2001, Caron et al.
799 2003).
800
801 Second, the kinds of interactions and feedback loops in which PAs participate may have
802 differing consequences for system resilience, particularly in relation to the spatial and temporal
803 scales of different actors and interactions. Although interactions between closely aligned
804 ecological scales and socioeconomic levels (e.g., the extent of grassland that is necessary for

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805 game viewing, the scale at which the manager can implement controlled burns, and the monthly
806 gate revenue of the PA) may dominate the 'usual' dynamics of the PA, very broad-scale or very
807 slow variables – acting either directly or indirectly - can have important implications for overall
808 system resilience, regime shifts, and management (Carpenter and Gunderson 2001, Lundy and
809 Montgomery 2010). For example, a gradual trend towards regional deforestation may affect
810 rainfall and temperature patterns within a PA, potentially leading to irreversible changes in
811 vegetation composition and long-term impacts on ecosystem service provision to surrounding
812 human communities. A closely related phenomenon is that of the shifting baseline, where change
813 that is slow by human standards may mean that degraded ecosystem states (e.g., reduced size of
814 fishes in marine PAs, or lower levels of forage in a rangeland) become regarded as normal. Slow
815 variables in particular can lead to surprises and push PAs into traps (i.e., states in which
816 feedbacks maintain an undesirable system state, such as a low-diversity thicket in a savanna
817 system) that can result in a loss of resilience and eventual collapse (Carpenter and Turner 2000).
818
819 Third, we would expect to find decay in the strengths of drivers (and related feedback effects)
820 with both distance and time. For example, the numbers of tourists visiting a PA decline with
821 increasing distance from airports and major cities (de Vos et al, in prep., this issue). Remote PAs
822 thus experience lower human impacts and are managed differently from those that are more
823 accessible. Similarly, while path dependencies may be important in understanding the current
824 locations of PAs, their influence also diminishes with time. For example, many southern African
825 PAs were originally set aside for hunting (rather than exploited for farming) because of the
826 presence of sleeping sickness, malaria, and tick-borne diseases. Tsetse flies have been eradicated
827 in some areas and their distributions, and those of malaria vectors and ticks, are likely to change

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828 further as the global climate is altered by people (Rogers and Randolph 1993, 2000, Cumming
829 and Van Vuuren 2006), making all three kinds of disease increasingly less relevant to the
830 location of PAs. For PA resilience, the principle of time- and distance-based declines in driver
831 and feedback strengths suggests that PA resilience will correlate with both ecological and
832 socioeconomic connectivity, but in different ways for different drivers, depending on whether
833 resilience is enhanced or reduced by the distance effect. Remoteness may result in fewer visitors
834 and lower economic resilience, for example, but may also reduce the potential impacts of such
835 factors as poaching, pesticide use on neighbouring farmland, and water extraction outside the
836 PA.
837
838 Fourth, the resilience of a complex system should correlate to its size; larger and older PAs, and
839 those established areas that involve more people, should be more resilient (although not
840 inevitably so). Note that we use ‘older’ here to refer to PAs that have had natural habitat cover
841 for a longer period of time, and in contrast to areas that are reclaimed or restored from farmland
842 or other land uses; some newly proclaimed PAs may have ‘old’ ecosystems and ‘young’ social
843 systems. Larger, older PAs (1) will be more resilient to natural perturbations, such as fires or
844 pest outbreaks, by virtue of their naturally heterogeneous habitats and high species diversity; (2)
845 are more likely to contain effectively self-regulating food webs that include such elements as top
846 predators and megaherbivores; (3) are more likely to include natural resources that society
847 depends on or values highly, such as catchment areas, mountain peaks, or iconic waterfalls; (4)
848 will tend to have a greater diversity of stakeholders (since stakeholders are often accumulated
849 over time) and a stronger public interest and participation in management (being better known
850 and more likely to contain highly charismatic species), making it less likely that a PA is re-zoned

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851 or de-gazetted; (5) may have a history that invests them with greater cultural meaning (e.g., more
852 people remember childhood holidays there, and it may have achieved 'iconic' status, like
853 Yellowstone National Park or Kruger National Park); (6) will have larger sunk costs, in the form
854 of infrastructure and investment in the park; (7) are more likely to contain multiple IUCN
855 categories, thereby achieving multiple goals that different stakeholders might have; and (8) are
856 less likely to experience the level of social change that is needed to transform their management
857 or for them to be de-proclaimed. It is possible, of course, that 'revolt' processes occur that lead to
858 change in larger PAs, and/or that their size makes them a more obvious target for land
859 redistribution initiatives, but on average we would expect them to be more resilient.
860
861 Fifth, given the many different ways in which power relations work in different societies, the
862 relative importance of top-down and bottom-up influences is likely to be asymmetrical and
863 dependent on the context in which the PA exists. As we have shown in the three case studies,
864 understanding context-dependent factors is essential to the proper functioning of a PA.
865 Therefore, there are no governance panaceas for building PA resilience that can be applied with
866 equal success to all situations (Ostrom and Cox 2010). For example, in a nation with a weak
867 government, it may be very difficult to buffer PAs from higher-level influences (e.g.,
868 development pressures, resource acquisition by the rich and powerful, or regional conflicts) or to
869 implement policies and laws at scales relevant for effective PA management. Normative issues,
870 value systems, and attitudes will influence PA resilience. Incorporating stakeholders in building
871 local resilience, even where regional resilience is low, should be a major focus of conservation
872 efforts. Current thinking suggests that the growing role of NGOs, international agencies,
873 scientific groups and private operators should be explored in the context of the development of

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874 polycentric governance of PAs where community-based management, Integrated and
875 Conservation Development Projects and adaptive co-management approaches are promoted and
876 implemented. It is not clear yet, however, whether such consensus-based approaches will be
877 sufficient to maintain PAs in the face of demographic and globalization processes.
878

879 Our framework and proposed principles have implications for PA management and planning,
880 although the uptake and application of some of these insights might be challenging. Our case
881 studies show that PA managers and planners cannot afford to ignore either ecological or social
882 dynamics, or (more importantly) their interactions at scales and levels below and above that of
883 the PA. Analyses of the key drivers of change will assist with identifying the relevant scales of
884 processes that are likely to influence PA management and planning. Such analyses must be
885 undertaken with a clear idea of the PA's social-ecological role, goals, and objectives. When new
886 PAs are planned, emphasis on larger, multi-objective and multi-IUCN category PAs may lead to
887 improved long-term viability of the area. Cross-scale institutional linkages have the potential to
888 serve as a link between top-down and bottom-up influences. However, while incorporating these
889 elements into management and planning would be desirable, national and international legal and
890 political systems may not readily allow for adaptively managing PAs as interacting cross-scale
891 SESs (Garmestani and Allen in press). Similarly, institutional and cultural constraints may
892 further exacerbate the challenges of changing embedded management approaches. In particular,
893 many PAs have a top-down, command-and-control history and approach to management (e.g.,
894 Andersson and Cumming 2013, Goss and Cumming 2013). Challenging these legal, political,
895 institutional and cultural constraints is paramount for making PAs more resilient into the future.
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897 We have argued throughout this paper that understanding PAs as social-ecological systems is
898 integral to developing the approaches, and the science, that will be required to maintain PAs as
899 functional and effective conservation tools into the next century. While awareness of the multi-
900 faceted nature of PAs has been gradually building in conservation biology for many years, our
901 understanding of their dynamics is still weak in some areas, particularly in relation to quantifying
902 and managing the ability of PAs to withstand shocks arising from socioeconomic and
903 governance-related variance at higher and lower scales. Concepts from social-ecological systems
904 research that explicitly address cross-scale feedback loops and resilience appear to offer a range
905 of useful conclusions in this context, and we look forward to further growth in this important
906 area of research.
907

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1253 **Tables**

1254

1255 **Table 1:** IUCN protected area categories.

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IUCN Category	Description
Ia Strict Nature Reserve	Category Ia are strictly protected areas set aside to protect biodiversity and also possibly geological/geomorphical features, where human visitation, use and impacts are strictly controlled and limited to ensure protection of the conservation values. Such protected areas can serve as indispensable reference areas for scientific research and monitoring.
Ib Wilderness Area	Category Ib protected areas are usually large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, which are protected and managed so as to preserve their natural condition.
II National Park	Category II protected areas are large natural or near natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area, which also provide a foundation for environmentally and culturally compatible, spiritual, scientific, educational, recreational, and visitor opportunities.

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III Natural Monument or Feature	Category III protected areas are set aside to protect a specific natural monument, which can be a landform, sea mount, submarine cavern, geological feature, such as a cave, or even a living feature such as an ancient grove. They are generally quite small protected areas and often have high visitor value.
IV Habitat/Species Management Area	Category IV protected areas aim to protect particular species or habitats and management reflects this priority. Many Category IV protected areas will need regular, active interventions to address the requirements of particular species or to maintain habitats, but this is not a requirement of the category.
V Protected Landscape/ Seascape	A protected area where the interaction of people and nature over time has produced an area of distinct character with significant ecological, biological, cultural and scenic value: and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.
VI Protected area with sustainable use of natural resources	Category VI protected areas conserve ecosystems and habitats together with associated cultural values and traditional natural resource management systems. They are generally large, with most of the area in a natural condition, where a proportion is

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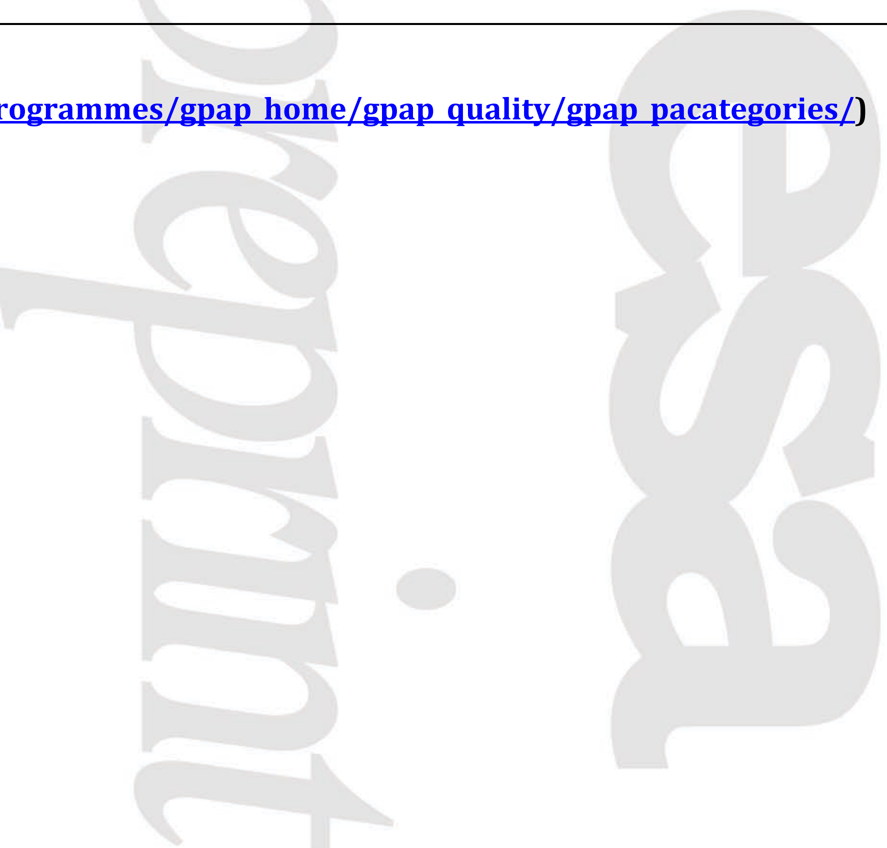

	under sustainable natural resource management and where low-level non-industrial use of natural resources compatible with nature conservation is seen as one of the main aims of the area.

(Source: http://www.iucn.org/about/work/programmes/gpap_home/gpap_quality/gpap_pacategories/)

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Figure captions

Figure 1: A summary depiction of Ostrom's SES framework. Different components of social-ecological systems (characterized as resource units, resource systems, governance systems, and actors) interact to produce outcomes. Each component is composed of numerous different elements. Although the framework indicates a role for cross-scale dynamics, this aspect of it has not been well developed in most applications. We note also that interactions --> outcomes includes interactions among (i) the ecological components of the system (e.g., predator-prey dynamics), (ii) the social components of the system (e.g., rulemaking), and (iii) the social and ecological components of the system (e.g., harvesting).

Figure 2: A multi-scale perspective of PAs as social-ecological systems, showing the relationships between the sizes, response times, and persistence times of different system elements. Note that individual elements in this figure are nested within each other. At each scale, Ostrom's SES framework captures some of the complexity of interactions between and across different subsystems.

Figure 3: Protected areas in the Western Cape, South Africa, showing the proximate, national, and international institutional context of each different area in geographic space. These different institutional levels interact with ecological and social processes at different geographic scales, as described in the text.

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Figure 4: The depiction by Poiani et al. (2002) of the components of an ecologically functional landscape. Different species have different habitat requirements and if a full range of ecological function is to be retained, habitat conservation must be undertaken in a nested manner, with wide-ranging, regional species having access to high quality patches at local scales. Note that despite its emphasis on functional landscapes, this figure does not directly include people and the scales at which they modify landscapes.

Figure 5: Summary of social-ecological patterns and processes at different scales. Pattern-process interactions across and between these different scales must be reconciled if effective, sustainable conservation is to occur. In addition, different actors and processes operating at the same scale may interact in important ways. This figure extends the depiction of Poiani et al. (2002) of the ecological components of a functional landscape.

Figure 6: Timeline showing changes in and tenure/land use and wildlife and livestock populations in the GLTFCA between about 1830 and 2010. The 1890 decline in wildlife and livestock was due to the rinderpest pandemic. The early period was characterised by increasing ecological and social fragmentation, followed by TFCA formation and moves to reconnect landscape elements for conservation.

Figure 7: Overview showing examples of issues identified as particularly important in each of the three case studies at different spatial scales in ecological, socio-political, and economic categories respectively. The case studies are indicated on the left of the

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diagram (EC, Eastern Cape; CM, Causse Méjan; GLTFCA, Greater Limpopo Transfrontier Conservation Area). Note that (1) this list is not intended to be exhaustive; and (2) many of the issues that are indicated for individual case studies are also relevant to other case studies in the same compartment. For example, tourism & community upliftment are important in all three areas.

Figure 8: Diagrams presenting a dynamic perspective for each case study system: (a) Eastern Cape; (b) Causse Méjan; (c) Greater Limpopo Transfrontier Conservation Area. As indicated in the legend, the different colours for each box represent different kinds of system element (social, economic, and ecological) and arrows indicate interactions and feedbacks within and between scales. These elements are plotted on the notional spatial (on the x-axis) and temporal (on the y-axis) scales at which they exist. The lengths of the boxes are not drawn to scale.

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Fig 1

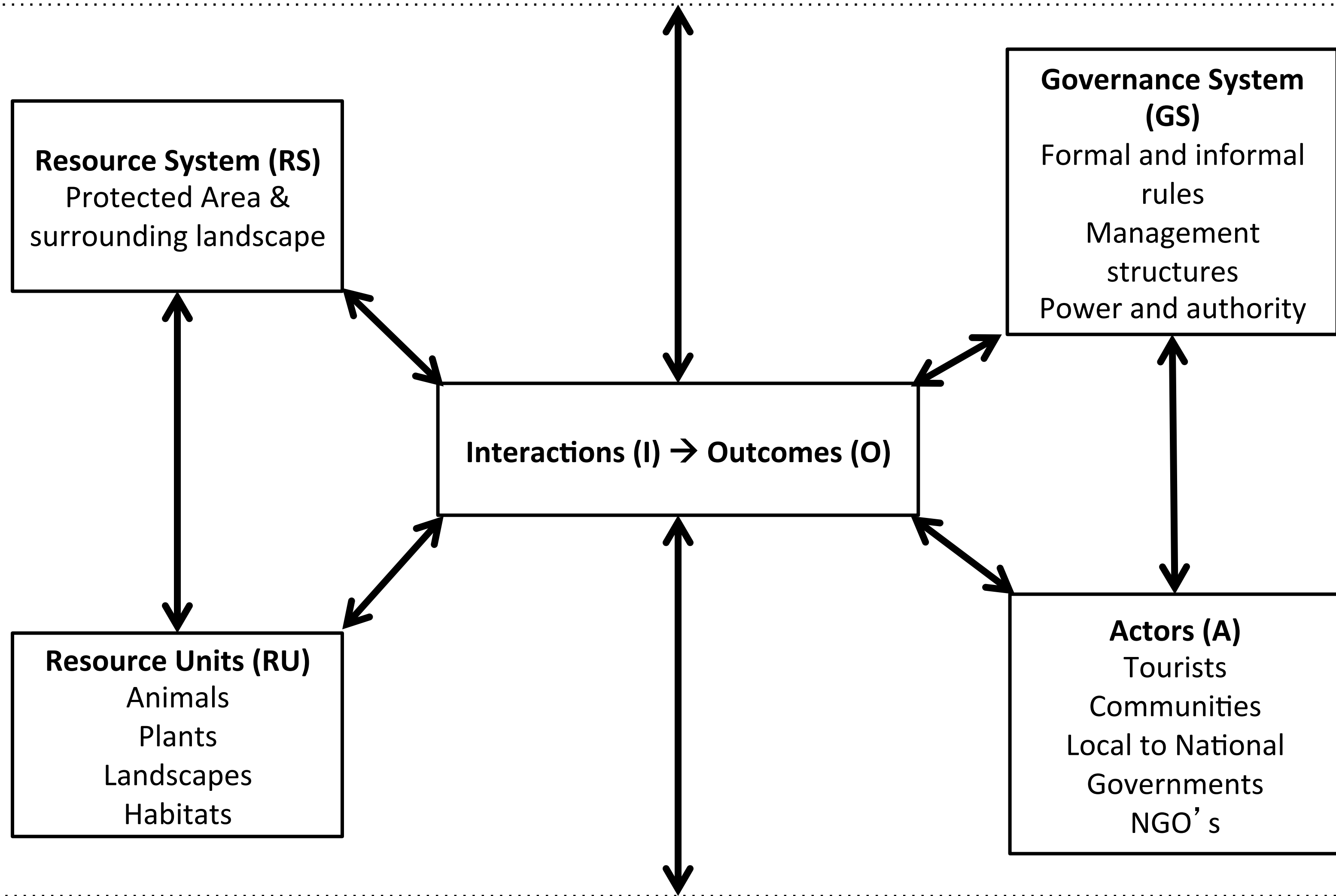
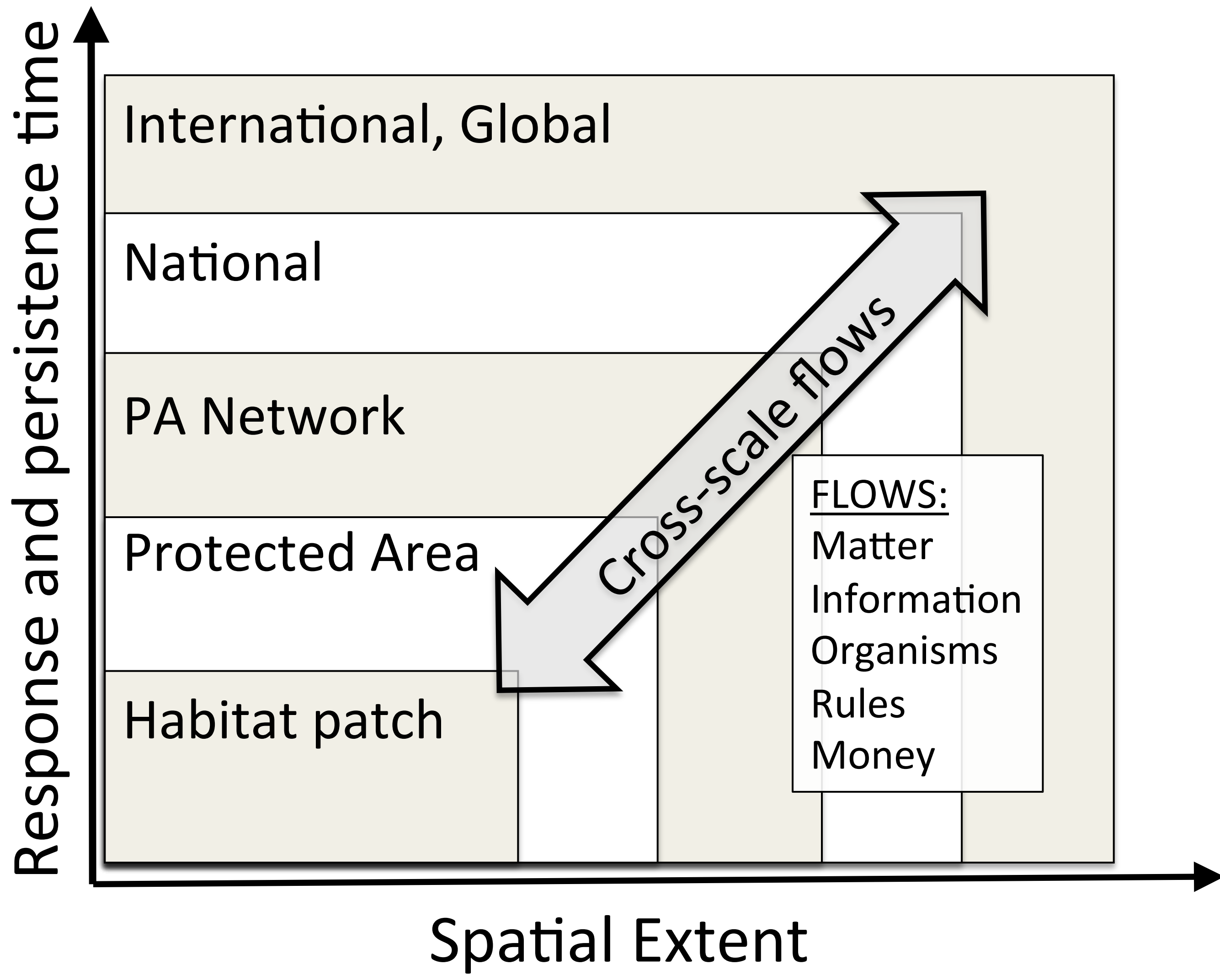


Fig 2



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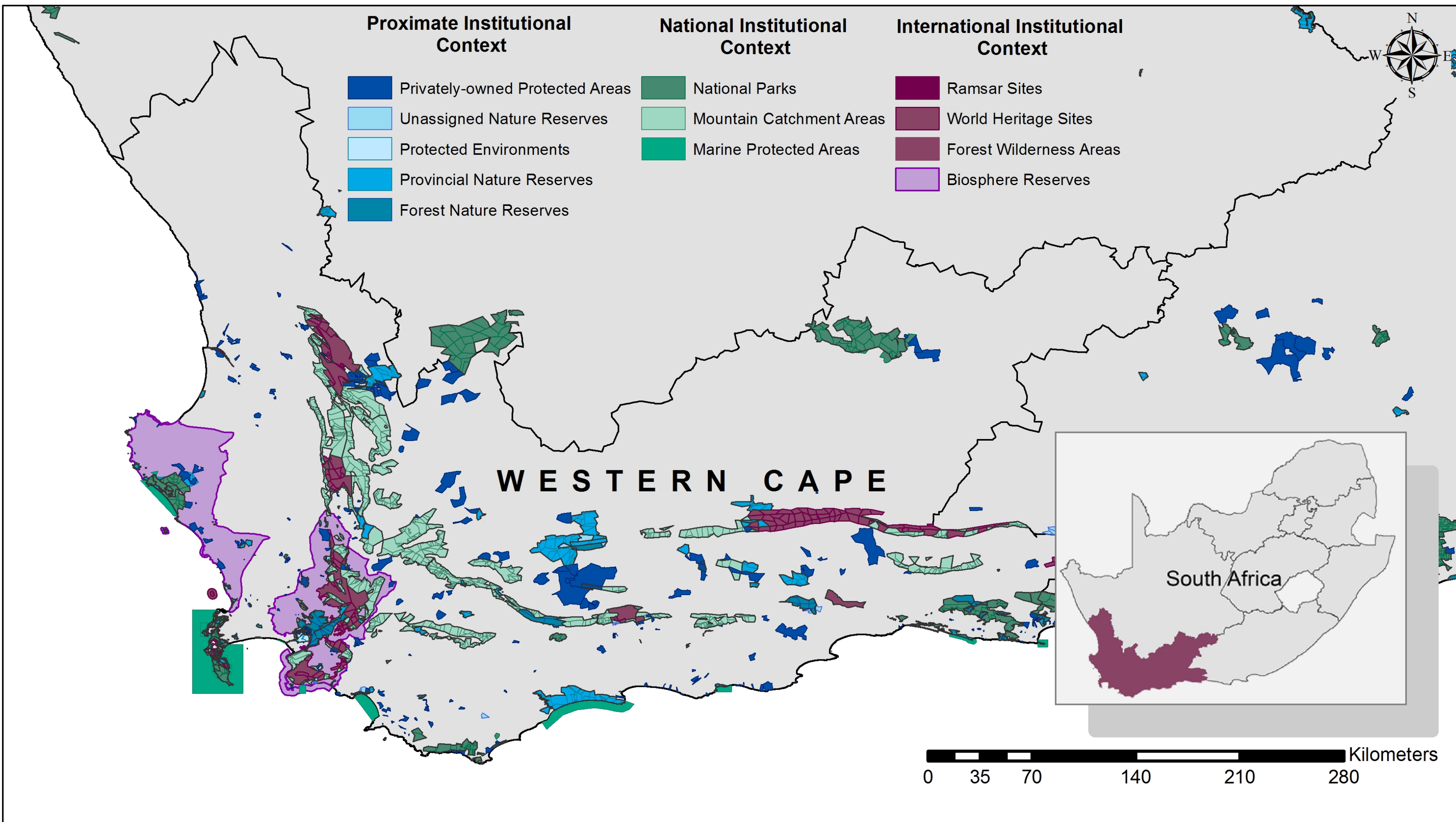

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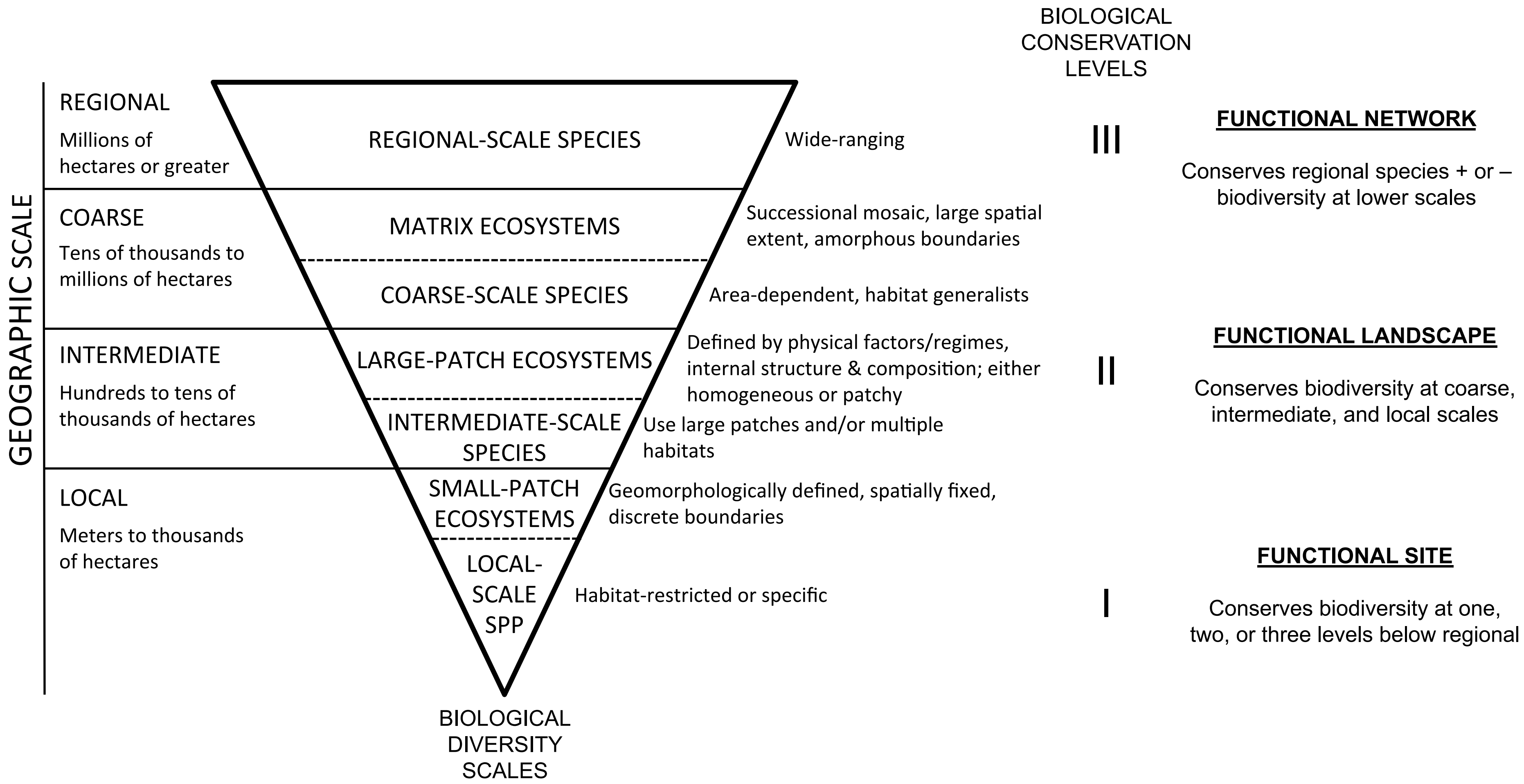

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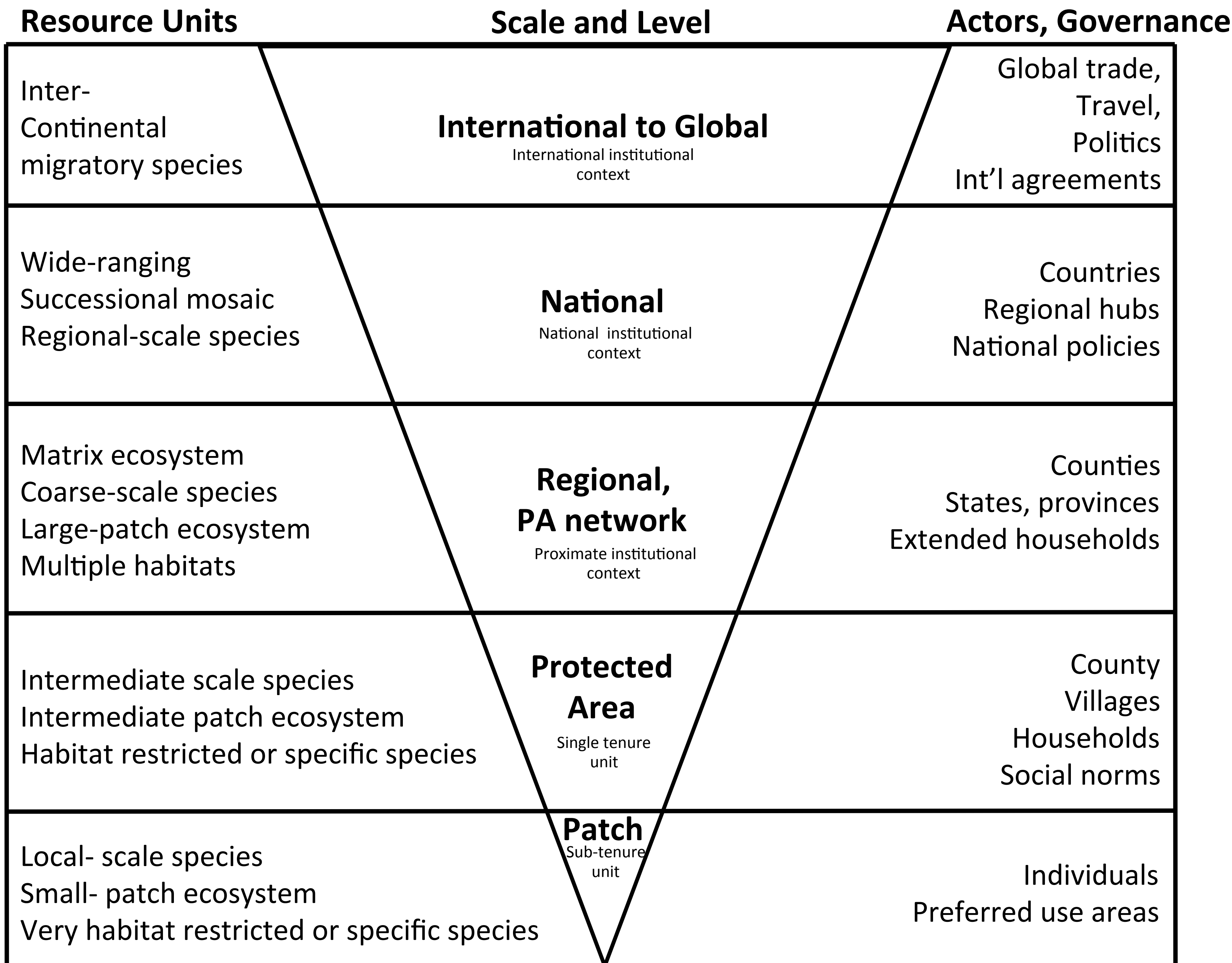
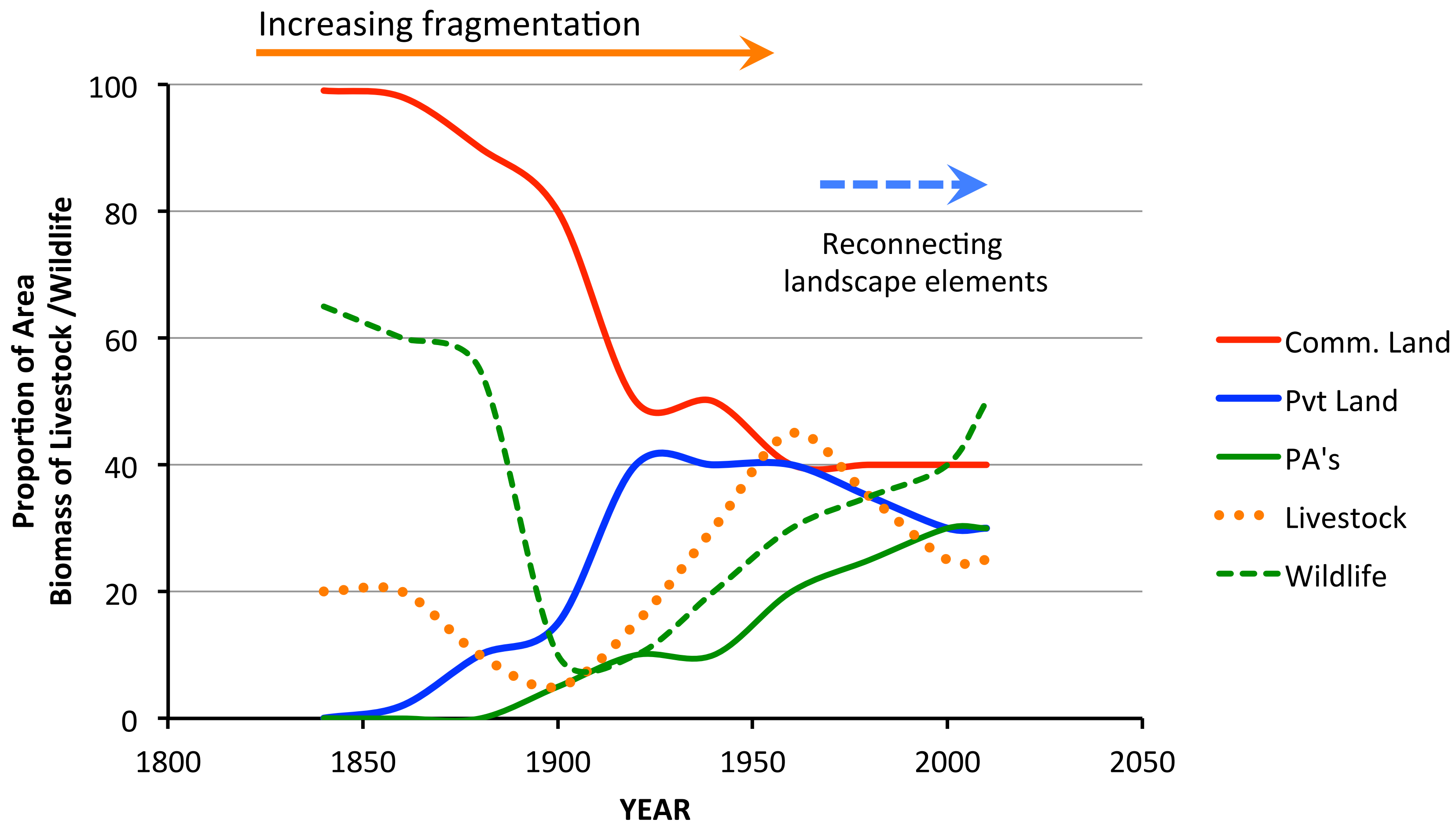


Fig 6



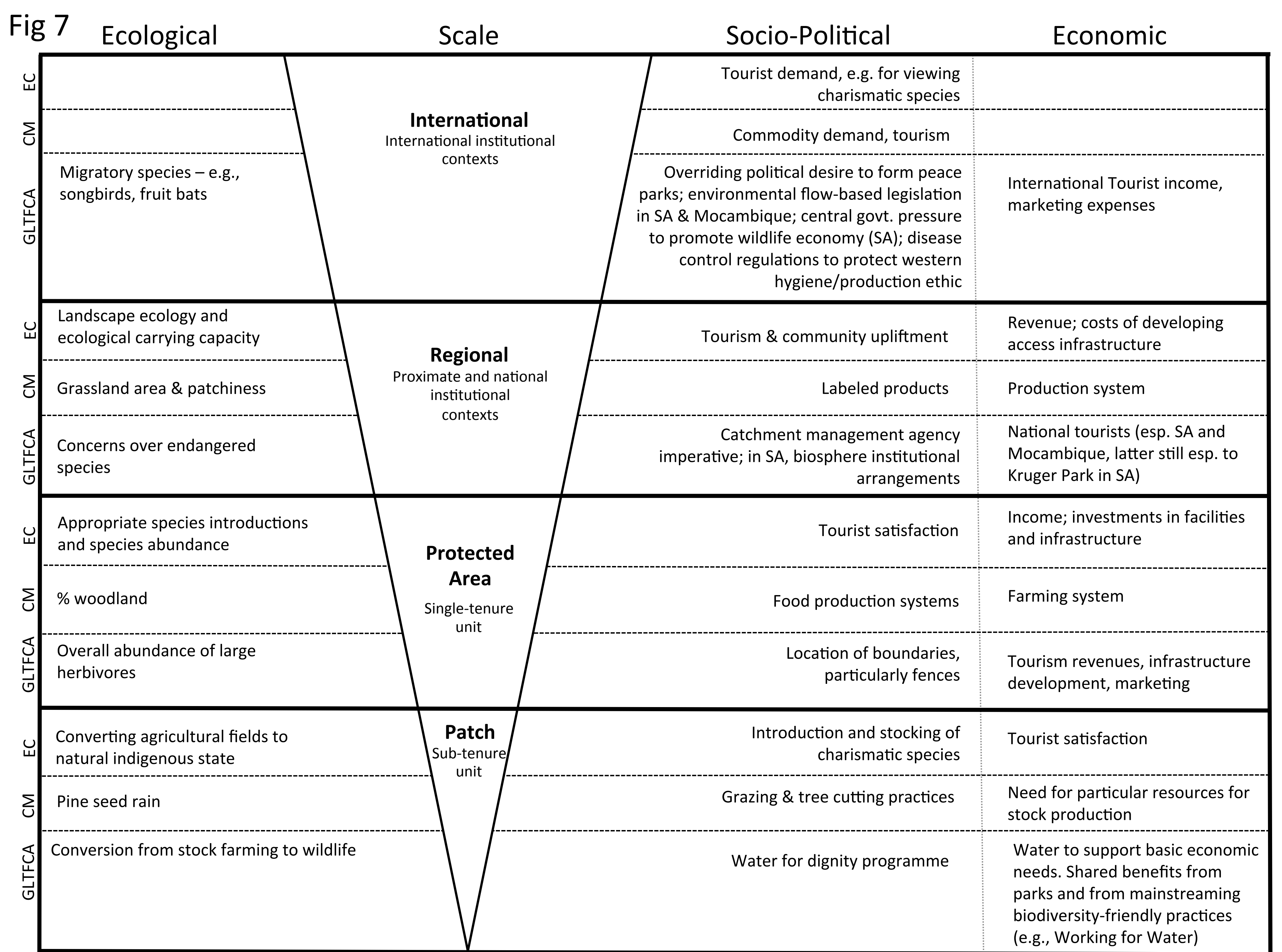
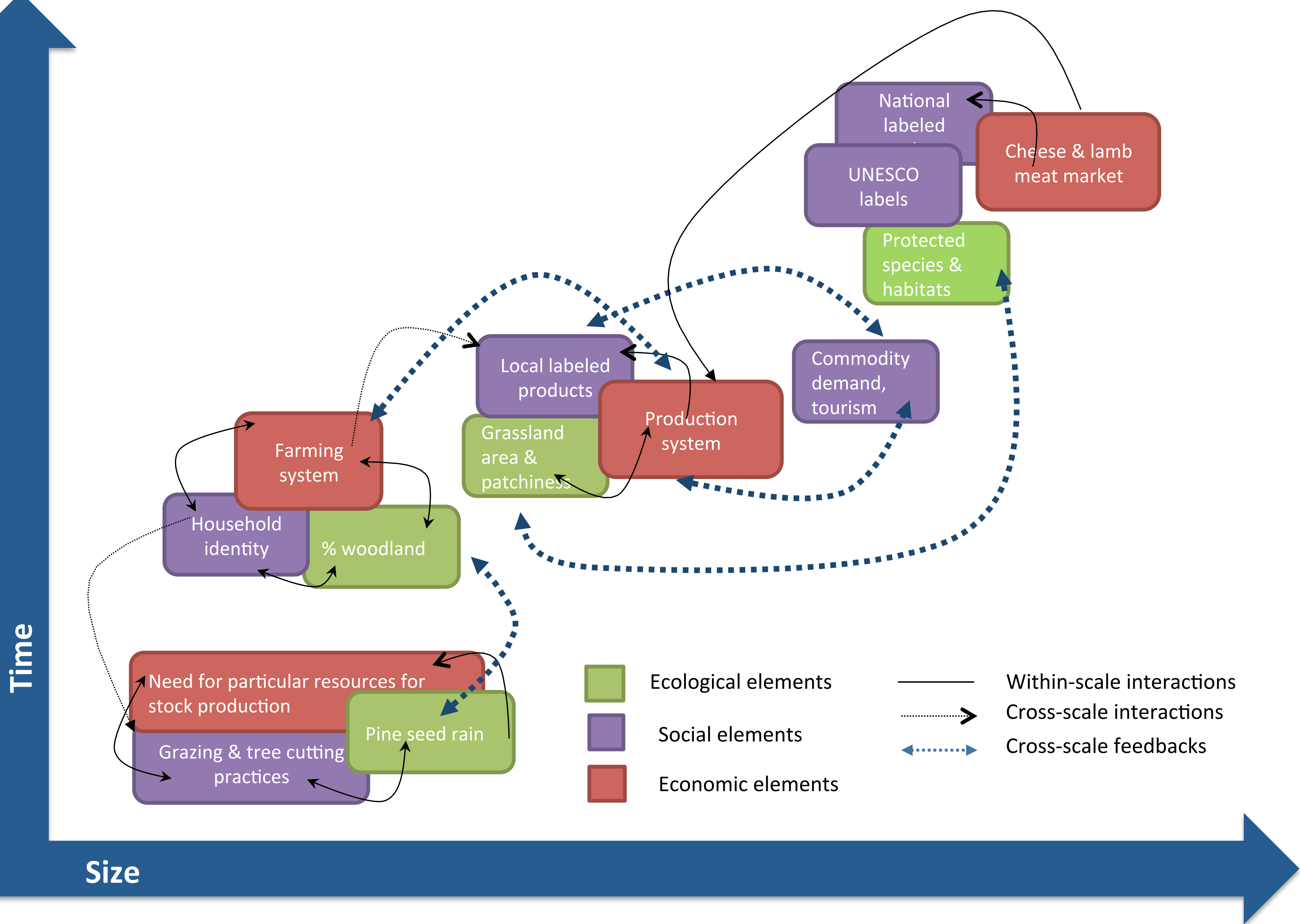


Fig 7
Ecological
Scale
Socio-Political
Economic
EC
CM
GLTFCA
International
International institutional contexts
Tourist demand, e.g. for viewing charismatic species
Commodity demand, tourism
Migratory species – e.g., songbirds, fruit bats
Overriding political desire to form peace parks; environmental flow-based legislation in SA & Mocambique; central govt. pressure to promote wildlife economy (SA); disease control regulations to protect western hygiene/production ethic
International Tourist income, marketing expenses
Regional
Proximate and national institutional contexts
Landscape ecology and ecological carrying capacity
Tourism & community upliftment
Revenue; costs of developing access infrastructure
Grassland area & patchiness
Labeled products
Production system
Concerns over endangered species
Catchment management agency imperative; in SA, biosphere institutional arrangements
National tourists (esp. SA and Mocambique, latter still esp. to Kruger Park in SA)
Protected Area
Single-tenure unit
Appropriate species introductions and species abundance
Tourist satisfaction
Income; investments in facilities and infrastructure
% woodland
Food production systems
Farming system
Overall abundance of large herbivores
Location of boundaries, particularly fences
Tourism revenues, infrastructure development, marketing
Patch
Sub-tenure unit
Converting agricultural fields to natural indigenous state
Introduction and stocking of charismatic species
Tourist satisfaction
Pine seed rain
Grazing & tree cutting practices
Need for particular resources for stock production
Conversion from stock farming to wildlife
Water for dignity programme
Water to support basic economic needs. Shared benefits from parks and from mainstreaming biodiversity-friendly practices (e.g., Working for Water)

Fig 8(a) Eastern Cape

Tourism, Community Upliftment
Carrying capacity
Revenue & costs of infrastructure development
Species Introduction
Tourist Satisfaction
Income & Investments
Tourism Demand
Land Conversion
Tourist satisfaction
Charismatic species introduction
Ecological elements
Social elements
Economic elements
Within-scale interactions
Cross-scale interactions
Cross-scale feedbacks
Time
Size

Fig 8(b) Causse Méjan



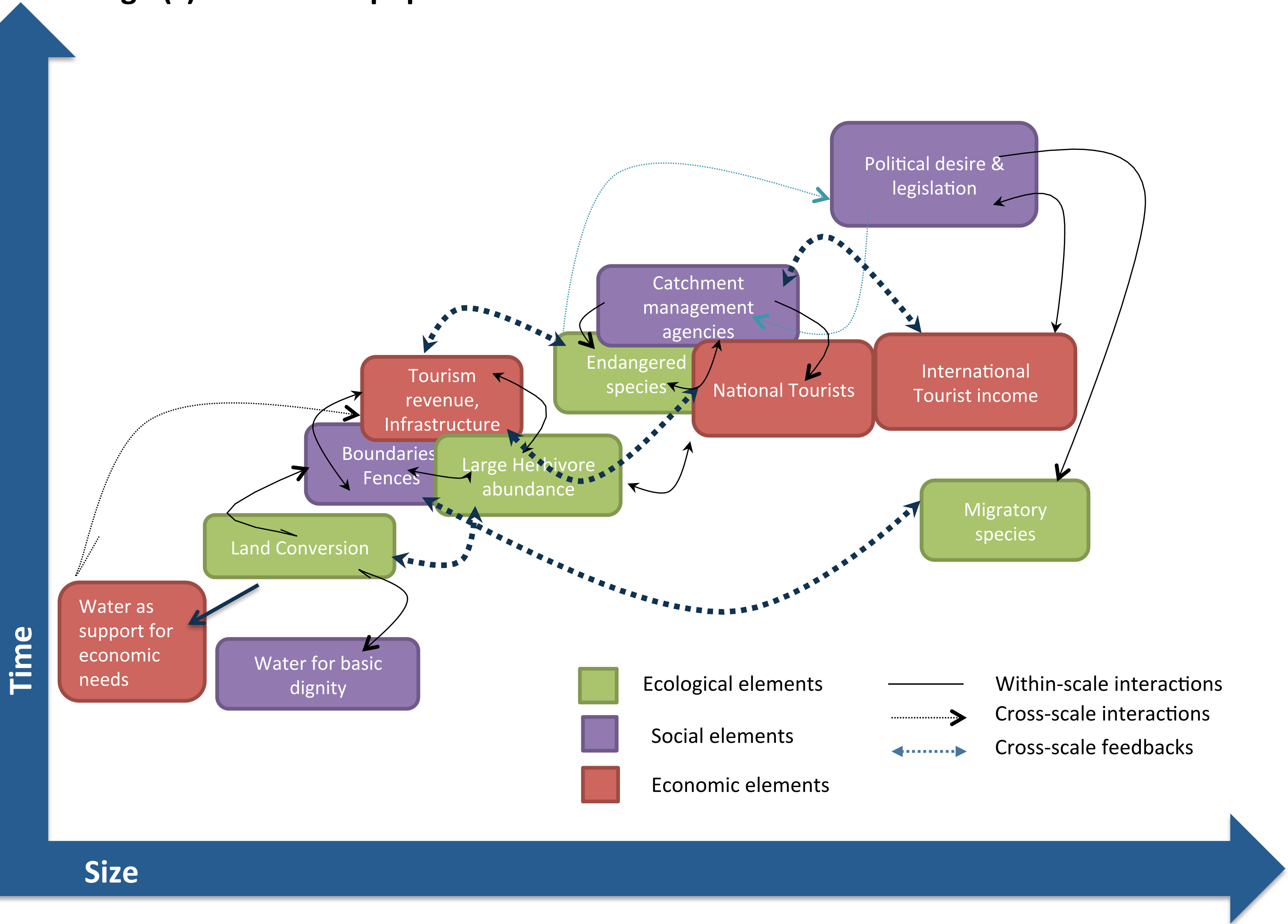


Fig 8(c) Greater Limpopo Transfrontier Conservation Area
Political desire & legislation
Catchment management agencies
Endangered species
National Tourists
International Tourist income
Tourism revenue, Infrastructure
Boundaries Fences
Large Herbivore abundance
Migratory species
Land Conversion
Water as support for economic needs
Water for basic dignity
Ecological elements
Social elements
Economic elements
Within-scale interactions
Cross-scale interactions
Cross-scale feedbacks
Time
Size