SELF-GOVERNANCE AND SYMBIOSIS: A SYSTEMIC APPROACH TO SOCIO ECOLOGICAL SYSTEMS RESILIENCE

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ABSTRACT

Several approaches understand resilience as a systemic attribute that emerges in the relationship between the system and its niche or environment; it is distinguished by an observer as a system's capability to persist or to maintain its intern change dynamics in consideration with (in some cases, despite of) environmental change dynamics. Described this way, resilience is an attribute related with viability, which implies considering aspects such as adaptability and transformability. Throughout this document we argue that it may be desirable to take into account a more holistic and complex way to approach resilience in Socio Ecological Systems – SES. Looking for a deep understanding of change dynamics in SES and what it may be a desirable change path for human societies, the paper introduces the symbiotic metaphor as a way to describe and understand complex relationships between human and ecological systems. We also argue that this approach brings up useful implications for self-organisation at various levels of systemic aggregation in human systems. Along the document we build a statement for changing resilience and governance analysis in terms of intern and environmental change dynamics, in such a way that change and self-organisation considerations are structured around relationship dynamics. The paper concludes showing how this approach has been useful for understanding change dynamics of two different SES in the Colombian Andean Eco Region and discusses the implications we may draw for future research.

INTRODUCTION

An important research path for contemporary systems approaches has been exploratory research searching for more systemic ways of understanding and managing complexity of messy problems related to the survival, resilience, and sustainability of human societies and institutions (e.g. to face the key challenges of climate change). Nevertheless, a majority of the most promising results of research in this field have taken a traditional understanding of resilience and sustainability, where either the socio-economic or the socio-ecological aspects affecting a SES are studied in great detail sacrificing sometimes other dimensions (e.g. the social, the spiritual, the aesthetics ones). In this paper we address this gap in the literature by exploring a more systemic way of describing and observing the dynamics of interactions between key actors in a SES. It includes revising existing concepts like resilience and viability with innovative concepts like symbiosis and explaining why this route of exploratory research makes sense.

We then present our research question, which is to explore why it would be necessary and useful to talk about symbiosis and self-organisation when considering resilience in SES. This question leads us to answer two embedded questions:

a. How the dynamic of interaction between actors in a SES affects its resilience?
b. How the symbiotic metaphor can illuminate studies of resilience and viability in socio ecological systems?

A review of literature in the fields of organisational cybernetics, second order cybernetics, and socio-ecological systems, allows us to clarify main concepts of self-organisation, viability, resilience, and symbiosis; this review also allows us to suggest a way to combine them to produce a coherent and robust observation tool to assess SES's resilience and sustainability.

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The methodology section will present a summary of our research approach and chosen methods, as well as the key arguments on why we have chosen an exploratory research, the methods and tools we have used to collect and analyse data, (comparative case study analyses); and the nature of the results achieved.

The following sections will first summarise and then compare two case studies of SESs that have been recognised as potentially vulnerable due to global climate change impact, in the Andean region in Colombia[2].

Finally the paper presents a thorough discussion on the issue, first conclusions reached and several key issues identified to design a research agenda to continue this path of research.

LITERATURE REVIEW

In this paper, we understand a socio-ecological system like a complex organisational network, composed by families, industries, and other types of institutions, operating in, or inhabiting in a shared eco-system. We reflect on essential elements and interactions in this complex organisational network and focus on the dynamic of interactions among key stakeholders of a particular eco-system, from the perspective of organisational and second order cybernetics. In order to fully describe and contrast our findings from the literature, we have divided this section in four themes: symbiosis, resilience, self organisation; and finally viability and sustainability.

Resilience

The concept of resilience has its origins in ecology and mathematics; from these perspectives resilience was at first related to the ability of a system to absorb perturbations and persist. In the context of human and social systems, resilience has been studied as one of three human dimensions relevant in terms of environmental change phenomena; the other two dimensions of interest are vulnerability and adaptation. The main research about vulnerability and adaptation has been developed from geography and anthropology; while resilience is related to persistence, vulnerability is related to discrete risks, and adaptability is related to long term change and adjustment (Janssen, Schoon, Ke, & Börner, 2005).

On the whole, due to time restrictions in vulnerability (discrete events) and adaptability (long term), resilience is considered as a useful concept to understand change dynamics in different systems. Therefore, this systemic property became the nuclear concept for the Resilience Thinking Paradigm (Walker & Salt, 2006). This paradigm is oriented towards the study of a SES as a unity, taking into account social and ecological aspects in the scenario; in its literature also presented tools for identifying interdependences, misfits, misconceptions, and best practices in the system (Andrade, Espinosa, Guzmán, & Wills, 2012).

The concept of resilience as proposed by Holling (1973) was criticized because of the emphasis in persistence and stability. Nonetheless, Gunderson and Holling (2001) develop the idea of persistence as referred to stability emerging from change. In a complementary approach, Walker, Holling, Carpenter, & Kinzig (2005) define resilience as the capacity of the system to absorb perturbations and reorganize while change is happening, in such a way

2 The data used and some of the analyses presented here come originally from the PhD field work of one of the authors (Guzman), supervised by the other author (Espinosa).

that the system conserves essentially the same function, structure, and identity. The evolution of resilience conceptualization is successful in addressing change in a more complex manner; however, it is missing several considerations about the environment, such as external change dynamics monitoring, organisational purpose and goals, viability, and desirability of persistence, among others. In terms of Lebel et al. (2006), it should be taken into account the purpose, actors' interests, information asymmetries, and power asymmetries around resilience. In this paper we propend for a more complex understanding of resilience, in such a way that desirable/possible futures and environment considerations become a central issue in developing resilience for human societies.

Symbiosis

In our search towards more sustainable ways of living as specie in planet Earth, we need to learn about our impact in the ecological niches we inhabit in and viceversa: the very symbiotic way in which we are co-evolving with our niches determine importantly our possibilities for survival in the long term. In other words, as Margulis (1998) and Perry (1983) explained, the only way for human societies to achieve long term sustainability is to re-conceptualize themselves as part of nature, subject to its permanently changing dynamics: the concept of symbiosis is a powerful one to demonstrate these possible trajectory for change.

Leonard (2009) explained that the notion of symbiosis means, co-existing together and it may happen through three different types of relationships: a) Mutualism – where there are benefits for both parties - not always equally or simultaneously; b) Commensuralism – where one party benefits and the other suffers no ill effects, and; c) Parasitism – where one lives off or is disadvantageous to the other, although if the parasite gets too greedy, both it and the host will die. Some species that live their symbiotic relationship become a separate whole: a very typical example is the mutual symbiotic relationship between the clownfish and the anemone. The clownfish attracts predators that are then stung by the anemone and they share the meal. Through its motions, the clownfish keeps the anemone's immediate area clean: protection is provided by the anemone, cleaning by the clownfish, and nutrition by collaboration between them.

Using the symbiosis metaphor as a way to observe and reflect human social interactions in a complex eco-system has already been done in several fields, like in Industrial Ecology, where the field of Industrial Symbiosis (IS) has been recently explored. Bansal & McKnight (2009) explain that IS focus more on the environmental and social issues, while other related approaches focuses more on environmental and economic issues within sustainability collaborative schemes. Walls & Paquin (2015) demonstrated an increasing interest in Industrial Symbiosis (IS) over the past two decades, funded in the enormous potential of IS to lower firms' and countries' environmental footprints. They suggest that an organisational research approach to IS is needed to understand how environmental and economic value can be created here. Chertow & Ehrnfeldt (2012) provided some generic criteria to design agile and flexible structures to allow self-organisation in IS, which seem extremely relevant when an evolving network becomes intentionally driven. These findings are also relevant to a broader study of SESs, where the nature of the interactions among industries and communities is even more complex, but in a context of dramatic climate change demanding collective action, may become intentionally driven, as the case studies below illustrate.

Self-organisation

Self-organisation has been a transversal phenomenon in study by different systemic, cybernetic, and complex approaches. The concept has its roots in the work of emblematic authors in each of these theoretical systems. Ashby (1962), von Bertalanffy (1968), and Beer

(1966) earlier works take self-organisation as a core concept of interest. We found three common elements in the authors when talking about self-organisation: first, the idea of organisation; second, the notion of organisational purpose; third, the system-environment relationship.

Organisation is addressed as a property of the system, which consists in the mutual conditioning of the constitutive elements of the system. In all of the cases, the authors talk about organisation as a property in the observer, not as an objective property in the system; every observer may see a different organisation in the same set of elements. Organisational purpose considerations bring authors around the notion of desirable and undesirable organisation; a good organisation would be that which allows the system to fulfil its purpose, while a bad one would apart the system from fulfilling it. It is important to mention that organisational purpose, as a system's organisation, is a property defined by an observer. Furthermore, taking into account that change is a permanent dynamic, a good organisation would allow a system to co-exist as time passes by, as a separate unit from its environment when it is desirable: this conversation brought up the idea of viability. On these grounds, Ashby (1962), von Bertalanffy (1968), and Beer (1966) talked about self-organisation as the autonomous formation of structural patterns (organisation); when developed as a capacity, self-organisation would be a basic and very relevant process to develop if viability is desirable.

In recent approaches, authors as Schwaninger (2006) and Espinosa & Walker (2011) highlight self-organisation as a mechanism for self-regulation, and as a process that would allow the necessary transit from local autonomous rules to global coherence. Both, self-regulation and global coherence with local autonomy would be *sine qua non* properties in Beer's Viable System (Beer 1972, 1979). As a particular contribution, Espinosa & Walker (2011) argue that hierarchical approaches have failed in addressing global environmental change challenges in a rapid and effective manner; thus, the authors propose that self-organisation, as a bottom-up phenomenon, may contribute to strengthen social systems by increasing their resilience to global climate change dynamics.

We consider important to emphasise that, when talking about human systems, it is possible to find undesirable self-organized dynamics. For example, a violent conflict development as a self-organized process has several negative consequences for most of social actors. In the same line, the way in which criminal organisations learn and transform themselves to successfully evade external control systems reflects an undesirable self-organisation process. Specifically in SES, it is possible to find undesirable self-organisation when patterns of interaction increase human vulnerability to specific climate change events or threatens the ecological sustainability, hence, socio-ecological viability. The examples above allow us to propose that when talking about self-organisation in human systems it is important to draw some conversations with different actors about ethics, common wealth, and social wellbeing. We would provide later some examples where climate changes threats are creating a context demanding collective action, so the SESs need to be self-managed, that is, become intentionally driven.

Organisational viability and sustainability

In this paper we have chosen the theory of organisational viability (the Viable System Model) – reinterpreted under a second order cybernetic lens, and applied in the context of sustainability – see Espinosa & Walker (2011) to reflect about resilience and symbiosis in socio-ecological systems. It develops further previous research where this way of understanding viability and sustainability has proven very useful to explain issues of self-governance in complex organisational systems (Espinosa & Walker, 2011).

Beer (1972, 1979) originally defined a viable system as a system able to adapt and to maintain an independent existence as it co-evolves with a changing environment. A viable system is always embedded in and composed of other viable systems: one of the biological mechanisms for survival is to develop viability in every part of an assembly of nested viable systems. He first suggested the idea of understanding communities as complex systems co-evolving with the environment, whose interactions could be mapped with Ashby's laws of Requisite Variety. We have developed further this idea and provided examples of application of this way of understanding a community in an Irish eco-community (Espinosa & Walker, 2011, Ch. 4; Espinosa et al., 2011; Espinosa & Walker, 2013).

We also provided a case study of a VSM intervention in the Colombian National Environmental System, which inspired an alternative way of organisation for the environmental network (Espinosa & Walker, 2011, Ch. 4). This research opened the path for exploring, with the same models and tools, an even more complex organisational system: the organisational network co-evolving within a particular SES. Guzman (2015) progressed this research by linking it with insights from socio-ecological systems and second order cybernetics theories.

Guzman (2015) provided further methodological guidelines to facilitate self-organisation in two Colombian SSEs, aiming to improve each of the SESs capability to manage themselves on crucial issues affected by global climate change. In this paper, we want to continue our previous studies by exploring in more depth the ideas of resilience and symbiosis within this generic approach to organisational viability. We want to explore innovative ways to observe resilience, self-organisation and sustainability of the dynamic relationships between key actors in a particular SES. We will suggest new research routes to progress this particular way of explaining resilience and self-organisation, by linking them to core issues of network governance in socio ecological systems striving for their long-term sustainability.

Lessons from the literature review for SES analysis

We may draw lessons from literature about each phenomenon described above. First, we want to highlight that resilience literature should include considerations about the future and the environment in a more complex manner; resilience, as described in the literature, is more related with flexibility than with adaptation or viability. In other words, a flexible system can resist perturbations and return to an original state; in contrast, an adaptive system incorporates characteristics of the relation with the environment, not to anticipate or resist the future, but to establish relations in the present oriented towards future considerations. In a SES context, we consider appropriate to ask questions about the manner in which the human system wants to establish and maintain a relationship with the ecologic (host) system. From this perspective, increasing a SES resilience means thinking about the relationships content in the present and looking to the future.

Following these ideas about resilience lead us to a symbiotic metaphor. When we ask about how the relationship between human and ecological systems should be, we want to propose that this relationship may be sustainable in the long term if it creates benefits for both of the systems. In most of the cases, the relationship as established right now describes a parasite relationship, so it is possible to assume that the relationship may not be sustainable in the long term. At this point, we consider important to retake Beer's (1972, 1979) idea about the link between self-organisation and a system's attributed purpose; if it is desirable for the human system to maintain mutual benefit relationships, we can propose that this is possible when local rules are coherent with global dynamics and when these dynamics facilitate systemic viability.

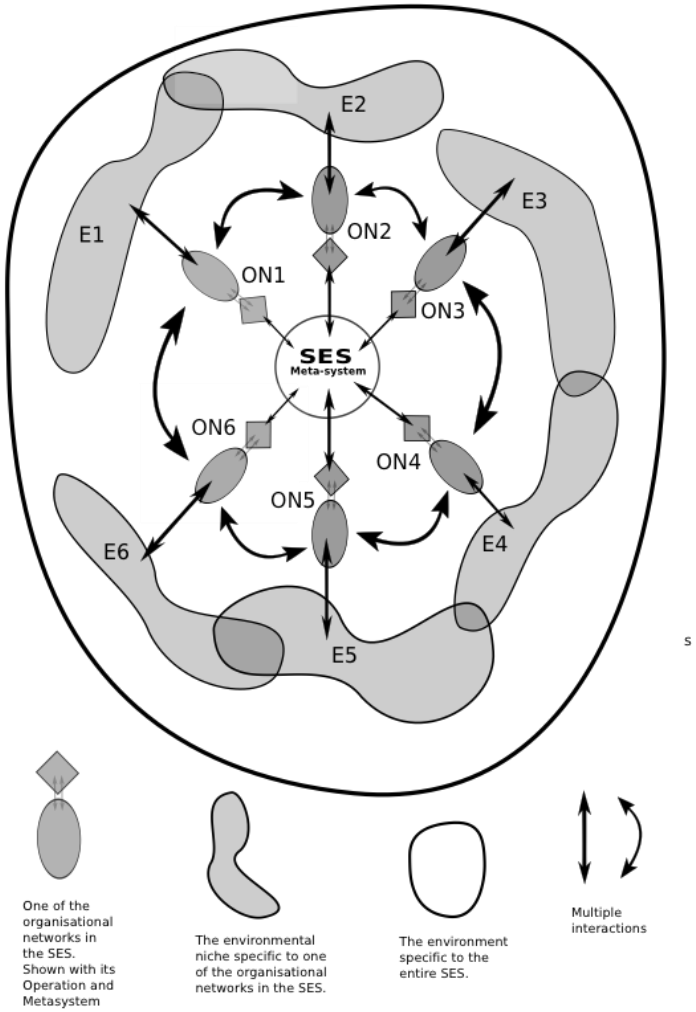
METHODOLOGY

In this paper we choose a systemic theory of organisational viability (the Viable System Model) applied in the context of sustainability – see Espinosa & Walker (2011) as a meta-language to explain main issues of self-organisation and self-governance in complex socio-ecological systems. We contribute to previous research, by adding the idea of symbiosis to strengthen our understanding of the intricately intertwined nature of our being in a particular niche and sharing its ecological services among key actors. This metaphorical way of understanding co-evolution allows us to explore even deeper the idea of resilience of a particular community co-evolving with a changing SES.

Such types of observations and reflections are particularly relevant in the context of climate change, where abnormal, sometimes abrupt and dramatic changes take place (see Bohorquez and Espinosa, 2015). By using it as a shared language to address main issues of resilience and self-organization, we suggest a heuristic to compare resilience capabilities in two complex socio-ecological systems. As an exploratory study about resilience and symbiosis, we aim to build up in previous research exploring ways of addressing issues of complexity and sustainability in organisational systems, to the context of organisational networks sharing a particular niche. We emphasize the description and understanding of dyadic relationships between actors, groups and more generically, between the socio-economic and ecological systems, aiming to produce a common reading of the health of the SES. We believe that this route of analysis will serve us to structure a research agenda to learn more about self-governance in socio ecological systems, from a complex systems perspective.

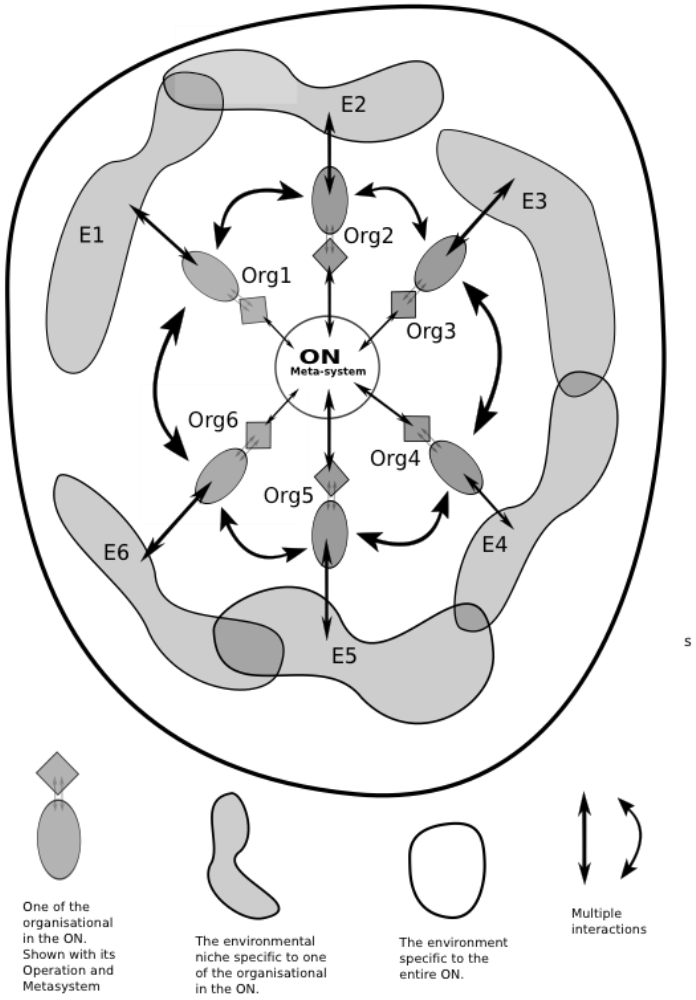
Figure 1 and 2 below presents a conceptual model of a SSE as a viable system, at two levels of recursion: the first one is at the level 0 of recursion at the SES and represents the different types of organisational networks that operate inside the boundaries of the ecological niche (all types of organisational networks; social, family, industries, government, citizens associations, etc). It involves both the ecological and socio-economic systems inhabiting and sharing a particular SES. These systems are connected configuring transformation systems; for example, the onion industry is embedded with the water cycle in one transformation system. The system is taking both, ecological and socio-economic inputs, and producing outputs at ecological and socio-economic levels. The focus of analysis is in the health of the dynamic of the interactions among key actors at each level. In VSM language, each of the actors is a System 1, embedded all together at different levels of embeddings. They act in a self-organised way as individuals and organisations of all types (industrial, governmental, community associations, NGOs, etc); but with reference to the health and long term viability of their SESs, they may or not engage in conversations and actions to agree collaborative actions to protect and enhance their SES's sustainability.

Figure 1. A SES at recursion level 0



Recursion level 1 of the SES includes a particular organisational network (e.g. a diary farms association; a community association. Etc). It describes the associated organisations, which may have strong or weak ties. The meta-system linking them may be from just a particular share of the market and conditions to operate on it; it may be incipient (weak ties) or more robust (e.g. sharing collaborative projects and knowledge resources). Figure 2 presents such network. This relational dynamic can be also observed at a dyadic level between humans, groups, organisations, or between the socio-economic system and the ecological system, as described above.

Figure 2. A SES at recursion level 1



We use this interpretation of the VSM as a meta-language to explain main issues of self-organization and self-governance in complex socio-ecological systems. By using it as a shared language, we manage to address main issues of resilience and self-organization in SES with a unique and truly systemic lens. For analytical purposes, we suggest a few tools to compare resilience capabilities in two complex socio-ecological systems. They are complementary to the 'Methodology to support Self-Transformation', which is focused on supporting double loop learning about sustainability and viability at different scales of networked organizations from local to global: – see Espinosa and colleagues (Espinosa et al, 2004; Espinosa, 2006; Espinosa et al., 2008; Espinosa & Walker, 2011; Espinosa et al, 2014).

Appendix 1 presents a framework to assess self-governance from this perspective, which has been used in several organizations, communities and organizational networks (Espinosa & Walker, ch 3-5; Espinosa, 2015). It is though, focused on self-governance of each of the organisations or social groups inhabiting a socio ecological system; in this framework, self governance is also referred to self-organisation and self-regulation dynamics at the individual-human level. Nevertheless this framework does need to observe and understand also the dynamics of the relevant actors with their ecological niche. For that purpose, we suggest here a new tool, which allows us to combine resilience and governance analysis in terms of internal and environmental change dynamics: the needs for change and for self-governance are then structured around relationship dynamics. To collect the data required for this type of

analysis, Guzman developed several field visits, oriented to modelling the SES through different qualitative tools: group sessions and interviews. The methodological strategy was oriented to fulfil two goals: first, establishing a relational base for talking freely about the problems related with each SES; second, creating a context to agree on the ecosystem services use and to discuss the best and less desirable scenarios for the sustainability of the SES.

In the following sections we present a comparative analysis of two Colombian SESs that are very vulnerable as a result of both global climate changes and industrial and socio-economic developments. Once presented and compared these case studies using the suggested tools, we'll present conclusions about the possibilities that this research route opens for us. As an exploratory study about resilience and symbiosis, by proposing and testing this new ways of understanding resilience and its associated tools, we aim to structure a research agenda to learn more about self-governance in socio ecological systems, from a systemic perspective.

CASE STUDIES ANALYSES

Both Fuquene and Tota lakes in Colombia, have been signalled as extremely vulnerable to global climate change negative impacts. We have already presented a preliminary analysis of the Fuquene Lake SES in Andrade et al (2012). Here we summarised more recent findings, coming from Guzman (2015) doctoral research. Using the suggested conceptual model, to establish the analytical categories, we present in Table 1 a summary of the main findings regarding relationships dynamics, as well as a brief analysis from the symbiosis metaphor, and from the mentioned theories on self-organisation, and viability and sustainability. We end up summarising the main considerations for the resilience of each of the studied SES.

Lake Fuquene is one of the most relevant regions for the diary industry in Colombia: its SES has suffered important changes due to global climate change and its survival is in clear danger. We cannot say that the ecological system is bounded to disappear, but we can suggest that its identity is near to change: if the charge capacity is severally undermined the ecological system will not be anymore a lagoon. As a consequence, the relationship with the socio-economic system is bounded to change so on the whole the system may stop being a socio-ecological one.

In a preliminary analysis of this SESs we found that 'existing institutional arrangements and policies to prevent increase of such risks are either inadequate or not operating as effectively and timely as they should. The case study analysis highlights the limitations in current management practice in the region (i.e. top down approaches to deal with climate change risks' management; dislocated views of ecological and social processes; inadequate understanding of the need for adaptation, etc)' (Andrade et al, 2012). Tota, while it is also vulnerable to climate change impacts, is a better preserved lake: its industries are mostly fisheries, onion, and tourism.

Guzman's finding in his doctoral research included a valuation of the ecosystem's health, regarding capacity to deliver ecosystemic services. This is summarised in Table 2 below. It is notorious that Fuquene has a much worse capability for ecosystemic provision than Tota. We can also suggest that Fuquene has lost capabilities for fishing ecosystemic services delivery and its waters are badly contaminated in a way that does not seem easy to rescue. It has lost its capability for providing water for human and industry consumption, and has little capability for regulating the flows of water. All these ecosystemic services are still available in Tota; nonetheless, four of the most important ecosystemic services are provided in an acceptable manner. At this point it is important to emphasise that our methodology is not oriented to describe in advance future changes in each SES. We do know that different structural and parallel variables in each scenario are changing, but it may be useful to

implement prospective analysis methodologies with each community in order to create images related with possible futures and driven the actions in the present.

Table 2
Ecosystemic services supplying capacity.

Laguna de Fúquene	CPS	Lago de Tota	CPS
Water for productive systems.		Water for productive systems.	
Habitat for wildlife and biodiversity.		Habitat for wildlife and biodiversity.	
Fish production for artisanal fishing; local source of food for low income community.		Fish production for artisanal, touristic, and sport fishing; and intensive fish farming. source of food for low and high income community.	
Water purification trough water cycle.		Water purification trough water cycle.	
Water regulation for the valley, affluent and emissary rivers.		Water regulation for the valley, affluent and emissary rivers.	
Local water level regulation.		Local water level regulation.	
Water for human consumption.		Water for human consumption.	
Recreation, transport, and tourism.		Recreation, transport, and tourism.	
Soil fertility.		Soil fertility.	
Nutrient cycle.		Nutrient cycle.	

Note: Green: optimum supply; yellow acceptable supply; red: deficient supply.

Using Guzman's primary data, we have done a new analysis based on the reference framework resulting from the literature review – see Table 1 below. The table presents a description around the dynamics in the SES. This description follows a bottom-up reading, thus it starts by describing its relational dynamic and propose a classification as a type of symbiotic relationship. Next, we offer a diagnosis about the self-organisation patterns desirability and accordance with an attributed purpose: viability. And finally, we offer a discussion about resilience hypothetical implications, assuming that this phenomenon may be only observed in a complex manner through a long-term process of observation.

Table 1. Preliminary analysis from theoretical framework.

Scenario	**Fúquene Lagoon**	**Tota Lake**
Relationship dynamics description.	Social dynamic around ecological resources has become intensely conflictive. Most of social actors work as separate units with conflictive goals. Explanations about environmental deterioration verse around other actor's responsibility. Historically, there have been attempts to drain the lagoon in order to use the hydrological resource and farm the territory.	Social dynamic around ecological resources has become mildly conflictive. Several social actors work with each other to regulate and control environmental practices. Explanations about environmental deterioration verse around other actor's responsibility, as well as around lack of knowledge. Approaches to minimize conflict are made looking for mutual benefits.
Analysis from a symbiotic metaphor.	Dynamic between actors inhabiting the ecological system is competitive and conflictive. In this context, considerations about benefits for the ecological system derived from	Dynamic between actors inhabiting the ecological system is cooperative in several cases. The search for mutual benefits and actions to preserve environmental capital drives

Scenario	Fúquene Lagoon	Tota Lake
	human action are not likely to take place.	these relationships. Nonetheless, actors discourse is not reflecting considerations about returning benefits to ecological system, but to preserving it.
Self-organization implications.	Dynamic inside and between different systems at recursion level 1 reflects an acute socio-ecological conflict. Different actors offer explanations about how others actions put in risk the lagoon sustainability. The use of the resources is intensely oriented to individual benefit and does not recognize long-term dynamics or collateral effects of this use for the lagoon. Self-organization patterns are undesirable considering the viability of the SES as a goal.	Dynamic inside and between different systems at recursion level 1 reflects a mild socio-ecological conflict. Different actors offer explications about how own actions put in risk the lagoon sustainability. The use of the resources is intensely oriented to individual benefit but it does recognize long-term dynamics or collateral effects of this use for the lagoon. Self-organization patterns are desirable considering the viability of the SES as a goal.
Viability implications	Nowadays, the lagoon is surrounded by farms, houses, and other types of buildings. If we consider that the lagoon capacity for regulating water levels in the valley may be definitely undermined, we can assume that in a rain season the lagoon is going to retake its original surface. Today, lagoon surface is about 30 km^2; originally it was approximately 300 $km^{2.}$ If the social dynamic persists, the SES is not a viable one. Identity of the system is bounded to change in such a way that ecological system may not be able to host any human system, at least, in its original surface area.	As local action has been considering long-term implications of industrial activity, the regulation follows a bottom-up approach. For example, the trout industry association has given basis for regulating the activity by taking care of water quality levels. The SES may be a viable one, but it is necessary to gather human action around sustainability. It appears to be important to bring local and national government support to social self-organized action, as well as international cooperation.
Resilience considerations.	Human vulnerability is very high and SES resilience is diminishing in an important manner. Ecological system's capacity to provide ecological services is ending up.	Human vulnerability is not high, but not low. The lake looks like a resilient one, but it is important to note that water surface is decreasing. Ecological system's capacity to provide ecological services is acceptable, for now.

Viability Analysis

As seen in the table below, a vertical reading may suggest a transit from local dynamics to global emergent properties, so that parasite relationships gradually lead to resilience undermining. In a compared reading, we can suggest that a mild socio-ecological conflict dynamic offers a context in which self-organisation with viability considerations is easier to spontaneously happen.

Table 2 below presents in a simplified way, the main actors that the researchers identified in each of the organisational networks described above: the major players regarding SES's

health were identified through secondary sources, interviews and focus groups organised by Guzman as part of his doctoral research.

A quick comparison between them already gives us some clues regarding their resilience capabilities: for instance, the Fuquene network is clearly more influenced by industrial players (e.g. diary farmers) and government agencies (who control the floods of the Lake in wintery times); while the Tota network has more active participation of SMEs, mostly related with fisheries and tourism. Structurally, it is possible to observe patterns of interaction in Tota oriented to lake conservation, whilst in Fuquene actions are driven towards individual benefit.

In both cases, we have attempted a first viability analysis: once identified the many operational agents (Systems 1 in VSM language) active in the region, we went to describe using VSM categories those agents responsible for meta-systemic roles as well as the mechanisms in use for dealing with complexity of the SES: in this case all those that contribute with resources, norms, information and knowledge that might contribute to sustainable self management of the SES, are identified as meta-systemic roles. Table 2 and 3 presents an example of key roles and mechanisms in use at each SES, during the case study analyses.

Table 2. Fúquene SESs' organisational network versus ecosystems pathologies.

Actors	**Rol/mechanism**	**VSM type**	**Compliance and usefulness**
Environmental Regional Agencies	Convenio de Diversidad Biológica (ley 165 de 1994),	5	Adequate.
Environmental Ministry	Política Nacional de Humedales Interiores.	4/5	Adequate.
Environmental Regional Agencies	Plan Nacional de Manejo de Aguas Residuales Municipales – PMAR	4	Adequate.
Environmental Ministry	Decreto 155 de 2004, con el cual se reglamenta el cobro de las tasas por utilización de aguas superficiales.	3	Inadequate.
Dairy Farmers	Industry practices and political action.	1	Inadequate.
Local Environmental Agency.	Regulation and enforcement management.	3/4/5	Inadequate.
Regional Craft Association	Community practices and political action.	1	Adequate.

Table 3 presents a summary of the people responsible from different operational and meta-systemic roles in Tota.

Table 2. Tota SESs' organisational network versus ecosystems pathologies

Actors	**Rol/mechanism**	**VSM type**	**Compliance and usefulness**
Environmental Regional Agencies	Convenio de Diversidad Biológica (ley 165 de 1994),	5	Adequate.
Environmental	Política Nacional de Humedales Interiores.	4/5	Adequate.

Actors	Rol/mechanism	VSM type	Compliance and usefulness
Ministry			
Environmental Regional Agencies	Plan Nacional de Manejo de Aguas Residuales Municipales – PMAR	4	Adequate.
Environmental Ministry	Decreto 155 de 2004, con el cual se reglamenta el cobro de las tasas por utilización de aguas superficiales.	3	Inadequate.
Onion Farmers	Industry practices and political action.	1	Partially Adequate.
Fishing Farmers.	Industry practices and political action.		Adequate.
Tourism private organisations.	Industry practices and political action.		Partially Adequate.
Local Environmental Agency.	Regulation and enforcement management.	3/4/5	Inadequate.

Observing this table, we can come to clear conclusions regarding resilience and viability of each of the SESs. For example, the organisational network in Tota has got stronger S4 capabilities, while the one in Fuquene clearly lacks such 'collective intelligence'. There are underlying norms (S3) in both Fuquene and Tota that are negatively affecting long term viability of the SES. The role of farmers and the dynamics of their relationships with politicians are having also negative impacts at this SES which is not the case in Tota; over there, a more democratic, bottom up approach to caring for their SES's health is taking place and both communities and industries are more proactive and responsive to collective needs.

These conclusions are of importance for environmental policy making and strategy implementation in each SES: the study concludes that by creating contexts for local conflict solving, negotiation, empowerment, and decision making may be a key route of action in terms of developing social capital, understood as a society's capability to draw common strategies to fulfil collective goals.

DISCUSSION

The conceptual approach described in this paper, contributes to existing debates on self organization and complexity management, by offering:

- an innovative approach to complexity management in SESs, that offers more clear criteria for organizational network's design;
- a solid starting point for building a comprehensive toolkit for mapping the complexity and dynamics of key social interactions at the intra and inter-organisational levels within a socio ecological system;
- a systemic way of observing cooperation between stakeholders sharing a socio-ecological system; and analysing the symbiotic nature of their interactions and the possible effects of this collaborative (or not) network structure.

The suggested research agenda is for developing more structured analytical tools to support SES analysis, in particular regarding their will to contribute to long term sustainability of their shared SES. Such tools will be focused on improving capabilities for learning and adaptation, as shared decisions regarding viability and sustainability of particular eco-system services.

Our suggested conceptual approach and tools contribute to ongoing research on self-organisation and industrial ecology, as it complements what Chertow & Ehrfeldt have suggested – within the context of industrial symbiosis - as required typologies of roles and mechanisms to support self-organisation in networks striving for their sustainability. Our interpretation of the VSM offers criteria for intentional design of effective organisational networks, with an appropriate meta-systemic management. The suggested toolkit (VSM and related analytical tools) eases *comparative research* by providing a unique language to analyse *'equivalent empirical research'*.

CONCLUSIONS

We have here explained the design of an innovative research agenda to more deeply explore a SES. Such agenda should be focused on the research questions described in this paper, and it should take on board trans-disciplinary insights, to model and analyse SESs. We have shown here that insights from theories on self-organisation, resilience, symbiosis and viabiliity are key to progress the research agenda.

There is a need for innovative tools to analyse SESs health: we have suggested a cmbined methodology and tools, some of which have been experimentally tested in two SES in Colombia. The suggested research agenda includes further development and testing of the suggested combination of methodologies and tools. It might need refinement of some of the suggested tools and a more clear way to link analyses obtained by using each of them in a SES.

By following this research route we may improve our understanding of self-governance in SESs . In this paper we presented examples of observing two complex SESs - regarding their their sustainability and self governance challenges - and identified their ways of responding with different self-organising strategies to such challenges.

There are still open questions regarding comparability of case studies when the organisational systems involved varied importantly in types and scales; and lessons to be learned regarding capabilities for self-governance and self organisation.

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APPENDIX 1

A FRAMEWORK TO ASSESS SUSTAINABLE GOVERNANCE

(Espinosa & Walker, 2015)

Criteria	**Ways of addressing the criteria/ level of achievement**	**Poor**	**Good**	**Excellent**
Co-evolution with the Environment.	*Developing capacity to deal with core issues for sustainability at each level of organisation:*			
	Working out what matters;			
	Real Time information;			
	Closed Loop Information Flows for Effective Governance;			
	Responding to Changes in the Environment;			
	Environments for Decision Making.			
	Identity and closure			
Autonomy and Cohesion.	*Developing meta-systemic management to support autonomous communities/ organisations to sustainably self-regulate;*			
	Enhancing Operational Autonomy			
	Developing mechanisms to deal with conflicting interests;			
	To provide synergy to S1s;			
	To develop knowledge management systems on critical issues for sustainability			
	To provide closure on sustainability issues			
Recursive Governance.	*Linking the local and the global governance issues and decisions;*			
	Enabling conditions for sustainable governance at each level of embedded and embedding organisation.			