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Adaptive management of social-ecological systems: a review from Social Network approach

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Abstract

Context: The social ecological systems (SES), characterised by intertwined relations between humans and nature, have been studied by researchers from different disciplines in the last 20 years. The concept of SES has been used to explain resilience in the face of change, including ecosystem regime shifts, climate change, disturbances and stresses over agricultural systems.
Objective: This paper is a literature review of the contributions of Social Network Theory for the study of adaptive management of social-ecological systems, which is influenced by capacities of the social subsystem, such as learning, innovation and collaboration.
Methods: A research for peer-reviewed articles was carried out, totalling 46 scientific articles using the social network approaches for the analysis adaptive management. A complementary review of the main concepts discussed was also conducted.
Results: This paper presents the most relevant structural characteristics of social networks to explain systems' capacity to self-organisein order to adapt to crises and change. Individuals and institutions play different roles in co-management and governance processes, which is reflected in decision-making capacity, leadership and cooperation.
Conclusions: The structural features of social networks are associated with adaptive capacity of socio-ecological systems. The adaptive approach allows social groups and institutions to improve resilience in different management systems. The existence of polycentric structures, with well-connected nodes, indicates the heterogeneity necessary for experimentation and innovation, which can be ensured with adequate network coordination.

Key words: social-ecological systems, adaptive management, social networks, resilience.

Introduction

Social-ecological systems (SES) have been adopted twenty years ago as a framework to analyse resilience in local resource management systems. Since then scholars of different backgrounds have used the term in interdisciplinary research, most of the time without a clear definition (Colding & Barthel, 2019). Despite the complexity behind the diverse types and analytical perspectives of SES, the term was defined as "intertwined systems of people and nature", characterised by inextricable connection between both social and biophysical subsystems (Folke, 2016). As part of the social subsystem of SES, social networks have been associated with the performance of natural resources management, and their social linkages were considered essential for systems' capacity to adapt to change and to persist, the very capacity of resilient systems (Bodin, 2006; Bodin & Crona, 2009; Carlsson & Sandström, 2007; Olsson, Schultz, Folke & Hahn, 2003).

Research on resources management very often focus on adaptive management and adaptive governance approaches to explain resilience of SES, expressing different levels of system self-organisation to respond to crisis and change. Both can involve transformations in the social component of SES, provided by

experimentation, learning and collaboration fostered by social networks. In both approaches, networks function as a source of social memory and innovation necessary for adapting and building resilient systems (Folke, Hahn, Olsson & Norberg, 2005; Olsson et al., 2003).

Social network analysis (SNA) also provides variable perspectives and tools for studying social structures and relations among actors. Configuration of social networks might influence the performance of social-ecological systems in terms of adaptive capacity and resilience (Bodin, 2006; Carlsson & Sandström, 2007; Olsson et al., 2003). This review paper focus on the particular contributions of Social Network Theory to understand relations between social networks and adaptive management. We explore the most common characteristics and metrics of network structures and nodes, the role of social actors and their connections analysed in different SES.

Methods and methodological considerations

A research for peer-reviewed journals, articles, book chapters and open access content was conducted using Science Direct engine, filled with the term "adaptive management" and having as title, abstract or author-specified keywords the term "social networks". In total, 46 articles were found for a preliminary review. The references of the selected articles were used as research source to broaden the conceptual and theoretical analysis, as well as specific search for the main concepts under study. Only available articles which explicit contributions to understand the role of Social Network Theory to adaptive management of the different types of SES were considered.

The first search was not intended to be an extensive review, as "social-ecological systems" include a large number of topics, and researchers not always use the term to analyse their research objects even if that could be considered SES according to the most accepted definitions. Besides, it was detected that (i) there exists distinct conceptions of the SES approach; (ii) the terms "adaptive management", as well as "adaptation" and "adaptive capacity" were often adopted according to conceptions other than the resilience-related concept applied to resource management systems; and (iii) social network is often merely used as a tool for different research purposes, without a clear social network or social-ecological theoretical approach (eg. one article conducted a wild animal network investigation, not related to humans). For this paper, all types of SES were considered, according to a definition adopted in system theory and or resilience-related studies (see Folke, 2016). Articles in which there was not a clear concept or a relevant contribution to explain the relations of adaptive management with social network theory were excluded.

Results

Adaptive management and adaptive co-management: creating resilient systems

The adaptive management framework was introduced to study environmental management in face of change and uncertainty, and referred to previous theoretical contributions to systems theory, particularly to the concept of resilience applied to ecological systems – i.e. the capacity of systems to absorb changes to maintain their original state despite perturbations (Holling, 1973, 1978). Adaptive management depends on the ability of managers to learn and reorganise systems to achieve a desirable state (Bodin, 2006). A common trait of natural ecosystems, self-organisation is also observed in social systems, which have been analysed though the lenses of Social Network Theory in several studies which will be discussed further.

A function of the social component of SES, adaptive capacity (also called adaptability) is the capacity of actors to influence resilience, which is possible by learning, combining experience and knowledge and innovating to adjust their responses to changing external drivers and internal processes (Folke 2016; Folke et al., 2010). It determines whether or not a system can avoid crossing into an undesirable system regime, maintaining its state variables and functions (Walker, Holling, Carpenter & Kinzig, 2004). These resilience-related capacities were associated with structure and functioning of social networks.

Researchers created an index of adaptive capacity for a study applied to land managers in Karoo rangelands, South Africa, considering six traits: (1) personal control, (2) record keeping and monitoring, (3) learning, (4) innovation, (5) leadership and group participation and (6) diversity of income and land-use. The index was applied to three groups: one adopting a "holistic management", a particular model created to encourage adaptive management; the other group adopting conventional management; and a third one comprising all land managers. Then social Network Analysis was used to measure specific characteristics of the social networks, which were further compared with the previous analysis. Results showed that networks of "holistic managers" had greater density and cohesion than the ones of the other groups, reflecting their interactions, as they were used to request for advice, support for managing crisis, as well as their friendship and family ties (Villiers, Esler & Knight, 2014). In this case, a possible interpretation could be that adoption of a previous adaptive management approach influenced the first group to exchange ideas (they created study groups to discuss management practices). This movement could be conducive to development of trust, learning and innovation among "holistic managers", fostering adaptive capacity in social networks.

A study of governmental marine and coastal policies in the USA found that networks of management programmes showed higher degree centrality than non-management programmes, which were less prone to

adopt ecosystem-based approaches. Authors conclude that the perception of managers about the alignment of their programmes to the definition of ecosystem-based management influenced adoption of adaptive management practices (Dell'Apa Fullerton, Schwing & Brady, 2015) (degree centrality and other metrics are discussed in the following sections).

Collaboration between social actors has also been studied as a trait of adaptive management. Co-management (or collaborative management) is commonly presented as a type of process in which individuals and institutions deliberately cooperate and establish rules for managing common resources (Carlsson & Berkes, 2005). Tompkins and Adger (2004) explored the role of social networks in building resilience to climate change, distinguishing two fundamental network types in terms of access to power and representation (networks of engagement), and support given to participants in vulnerable positions (networks of dependence). Resilience building is expected to come up with the adoption of an adaptive co-management within the spaces of engagement and dependence, which would enhance relationships between resources users, collective action, access to technologies and the willingness to change and respond to climate stressors (Tompkins & Adger, 2004). Their case studies in communities affected by hurricanes in the Caribbean demonstrated that the consolidation of spaces of dependence enhanced community cohesion and communication. The authors also argued that the development of networks of engagement is critical to communities affected by climate extremes, as it is conductive to knowledge-driven processes fostered by interaction, deliberation and behavioural change.

Co-managment is thereby understood as the collaborative management of resources, a process that involves sharing of power and responsibility between social actors, usually the government and local resource users (Carlsson & Berkes 2003; Berkes, Colding & Folke, 2003). The interest of scholars in specific adaptative capacities in co-management networks led to the adaptive co-management approach (Bodin, 2006). Both concepts stimulate qualitatively dense debates about the role of actors and their ties, concerning power-sharing, trust relations and collective action (Bodin & Crona, 2009; Carlsson & Berkes, 2005). Analyses have been carried out using correlations of certain structures of social networks and qualitative data of social behaviour in function of the way people are connected (eg. Chaffin, Garmestani, Gosnell & Craig, 2016; Tuda, Karke& Newton, 2019).

Structural relational patterns of social networks

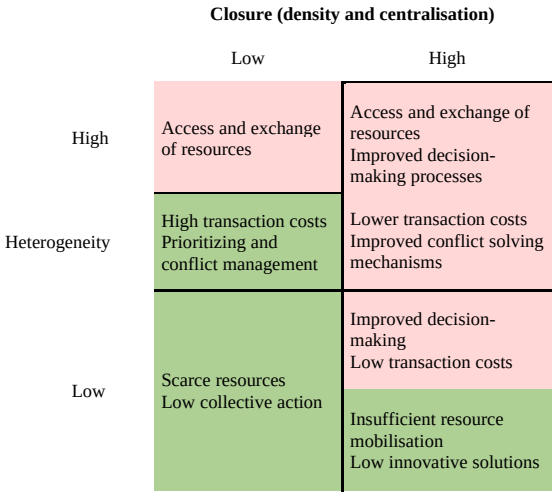
Social Network Theory has been used in interdisciplinary research to explain several social processes and relations such as social dilemmas, collaboration, generation of knowledge and innovation. It has been demonstrated that the mechanisms that explain engagement of social actors, their behaviours and certain management-related capacities are usually reflected in networks` structure, as well as functions performed by their nodes - individuals, organisations etc. (Bodin Crona, & Ernstson, 2006, 2006; Newman & Dale, 2005; Tompkins & Adger, 2004).

Social networks are understood as social structures made up by nodes, i. e. members of a group or community (individuals or institutions) connected via different types of ties in the form of information flows, exchange of goods, legal relations etc. (Carlsson & Sandström, 2007). There are basically two types of tie with respect to its function within the network: (i) a bonding link connects two nodes in closed, strongly tied groups, and it is usually found in homogeneous constellations inside a network; (ii) a bridging link is a weak tie between more distant and heterogeneous network members, who commonly tend to have different knowledge and access to distinct resources (Newman & Dale, 2005).

Network structural patterns are determined by their size and the characteristics of ties, being the latter classified as bonding or bridging ties. While bonding ties foster social capital, communication and collaboration, bridging ties are associated with innovation and diversity within a system, increasing access to resources and opportunities (Bodin et al., 2006; Carlsson & Sandström, 2007; Newman & Dale, 2005; Tompkins & Adger, 2004). The importance of a dynamic interplay between bonding and bridging ties (also called strong and weak ties) is a core issue both for community-based adaptive management and resilience building. A balanced relation between both types of links allows the necessary diversity and experimentation conditions, as well as trust amongst members, including nodes in different hierarchical levels and skills, enabling adaptive capacity and dynamic innovative responses to unexpected changes typical of resilient systems (Bodin & Crona, 2009; Newman & Dale, 2005).

Carlsson & Sandström (2007) argue that configuration of social networks is associated with performance in co-management of natural resources, affecting and being affected by institutional arrangements defined by a given problem of context. The performance of this co-management systems has influence on resilience of SES (see Table 1). Adaptive co-management systems could be affected mainly by two major structural features of the social networks: (i) high level of closure (measured by network density and centralisation, which is related to communication and collaboration between farmers, restraining opportunistic behaviour) and (ii) heterogeneity (existence of different set of actors which facilitates access to exchange resources) (Carlsson & Sandström, 2007). The attributes shared by central actors are also relevant to understand the role of nodes with influential positions in knowledge transfer processes and leadership strategies in different cases (Bodin & Crona, 2009).

Table 1. The relation between network structure and qualities of co-management systems. Redrawn from Carlsson & Sandström, 2007



Closure is indicated by network density, the number of actual connections divided by the possible number of connections, and its centralisation. Density is usually associated with fostering social capital and social memory, enhanced communication, favour collaboration (collective action) and restrain opportunistic behaviour. Centralisation is related to system's hierarchy and decision-making, but can also inhibit experiments and learning (Bodin et al., 2006; Carlsson & Sandström, 2007; Folke et al., 2010).

Betweenness is defined by how much each node contributes to minimize the distance between nodes in the network, and applied to the whole network to measure separation into smaller groups it receives the name of network modularity (Bodin et al., 2006). Betweenness indicates the capacity of forming multiplex groups connected to each other, which can develop distinct knowledge clusters, fostering resilience, although it can also have constrain building consensus among actors (Bodin et al., 2006). This metric is used as a measure of network heterogeneity, influencing the diversity of nodes and of roles played by them, and it is commonly associated with resource mobilisation and innovation necessary in co-management systems that cross organizational boundaries to access resources and knowledge (Carlsson & Sandström, 2007). The strength of the links between clusters also influence learning and the ability to transfer knowledge (Bodin et al., 2006).

Bodin et al. (2006) identified six features related to adaptive management of ecosystems (social memory, heterogeneity, redundancy, learning, adaptive capacity, and trust) and their respective links to social networks structure and their measures (Tables 2 and 3).

Table 2. Features identified as important for the adaptive management of natural resources and the ways in which they are linked to social network structure. Adapted from Bodin et al. (2006)

Features	Links to social networks structure			
	Density	Centrality	Betweenne ss	Reachability
Social memory	Many links with other individuals enhance collective memory useful in times of change	_____	_____	Access to many individuals enhances collective memory
Heterogeneity	Homogeneity of behaviour constrains innovation	_____	Diversity of groups enhances innovation	_____
Redundancy	Several actors cooperating to resolve the same problem	_____	Dependence of specific actors to resolve problems	_____
Learning	Improves knowledge transfer	Constrains experimentation	Improves knowledge transfer	Improves knowledge transfer
Adaptive capacity	Constrains decision-making and innovation	Improves coordination, rapid response to changes	_____	Decentralisation constrains collective action
Trust	Fosters community support to solve problems	_____	Separation of groups constrains community support	_____

Table 3. Examples of quantitative network measures and how they are related to different network characteristics. Bodin et al. (2006)

Characteristic	Measure
Density	Number of links divided by the number of nodes in the network.
Reachability	Diameter, i.e., the number of steps maximally needed to reach from one node to any other node in the network. Number of components. A component is an independent network within the larger network in which all nodes are directly or indirectly in contact with each other. If a network consists of more than one component, it is considered fragmented; the degree of fragmentation is quantified by measuring the number of components.
Betweenness	A measure that quantifies the degree of betweenness (Freeman 1979), i.e., how much each node contributes to minimizing the distance between nodes in the network (compare with reachability above). This measure can be applied to individual nodes, and can then be used to identify the actors that contribute most to linking the network. The measure can also be applied to the network as a whole to quantify the degree of modularity, i.e., separation into smaller groups or modules.
Centrality	The degree of centrality indicates how many links a node has (Freeman 1979). This measure can be applied to individual nodes or the whole network. A high degree of centrality for an individual node indicates that it has many links compared to other nodes. Centrality for the whole network indicates the tendency in the network for a few actors to have many links, e.g., a wheel-star structure.

The use of social network metrics and graphs to analyse management processes and systems' capacities involves complex variables which require from investigators to combine different qualitative approaches and theoretical research, as structures are frequently dynamic in

response to changing social and ecological contexts. Besides, structural characteristics have inherent juxtapositions (Bodin et al., 2006). A research with diverse actors including users of ecosystem services, associations, government, NGOs terrestrial and marine ecosystem revealed poor correlation of linkages between actors and the existing connections between actors that manage the same ecosystem services. The cohesive, centralized networks of governance did not necessarily represent, in this case, adequate connections between users governance processes that could hinder tacit knowledge necessary to adapt. However, authors make theoretical speculations that such network centralisation could represent an opportunity for institutional strengthening, promoting interactions to create more decentralised structures and exchange specialised knowledge (Alonso, Villasante, & Outeiro, 2015). In another study, bridging nodes of a fisher co-management network in Chile paradoxically connected local organisations to existing opportunities and, at the same time, made those opportunities more inaccessible due to the excessive number of nodes supplying different types of information. The complicated bridging ties with middlemen, governmental institutions and agencies provided all but valuable horizontal linkages of fisher organisations with each another (Marín & Berkes, 2010).

The role of individuals

Individual contributions to adaptive governance are largely discussed in social network theory and corroborated in empirical studies. Leadership, trust building, vision, and meaning are some individual traits that, together with social relations and networks, contribute to adaptive governance systems. Leaders are considered key actors for identifying opportunities and promoting organisational change necessary to governance systems (Folke et al., 2005).

Node-level metrics as betweenness and degree centrality are helpful to determine changes in a governance network, as these attributes can indicate increased interaction, trust, communication, collaboration and influence, although authors stress that these metrics cannot be used as exclusive predictors of the emergence of adaptive governance (Chaffin et al., 2016), as discussed further.

Using social networks metrics combined with qualitative methods, researchers have analysed individual behavioural trends within communities or groups. A study with private wine growers in California (USA) indicated correlation between the degree centrality of nodes and the probability of farmers to adopt identified sustainable practices associated with adaptive management in viticulture. Growers were separated in three different groups according to their perceived economic cost/benefits of the practices. Although all groups showed a positive association of likelihood to adopt practices with the number of network connections, this tendency was stronger for least costly practices (Hillis, Lubell & Hoffman, 2018).

The measure of individual parameters of nodes can also support interpretations of certain aspects of the whole network, as suggested by a study in rural areas in two water-scarce watersheds in Canada, where researchers used betweenness centrality together with cluster analysis to identify bridging nodes through which occurred diffusion of information and knowledge flows, associated with learning and adaptation processes. One major conclusion was that lack of bridging actors was constraining collective action and consequently adaptive capacity of the entire system. Despite the attempts of institutions of both watersheds to resolve the problem hiring external bridging actors for coordination and facilitation, system's innovation capacity was suffocated by high level of homophily and centralised power of specific brokers with poor understanding of solutions and local potentialities, the main cause of low effectiveness in water management processes (Horning, Bauer & Cohen, 2016).

A social network study using ego networks (centred in a specific individual) with landowners of a local forest cooperative in Wisconsin, U.S., exemplifies the importance of institutions in building strong ties and trust relations. Authors suggests that activities of the local cooperative have expanded members' strong ties (mainly with association staff) and their weak ties through greater interaction with other members (landowners). The study showed that, although there was an important number of ties with non-members, cooperative members perceived the association's staff and other membersasmost trustworthy in terms of the information provision than external actors (Rickenbach, 2009).

Adaptive governance: the role of institutions

As part of the debate on co-mangement of SES, scholars have been discussing the relations of structural features of social networks also from the perspective of social coordination. They refer to adaptive governance as being structures or processes of co-management that could create the means for the establishment of rules, decision-making and collective action (Folke et al., 2005). Authors explore the polycentric institutional arrangements in opposition to centralised structures, the former stimulating interactions across organisational levels which enhance learning, experimentation and collaboration associated with adaptive capacity of systems.

Chaffin et al. (2016) investigated relational patterns of institutional social networks during governance transitions in Klamath River Basin, U.S., with focus on changes that could determine the emergence of adaptive governance. The study focused on the basin governance network in three different moments – conflict, negotiation and agreement, between 2001 and 2010. The authors argue that, although increases in network centralisation and density often indicate increases in trust, communication, information sharing and knowledge production, such relation was not found in the case study. Network centralisation increased only between the two first phases, because during the

negotiation phase, organisations and stakeholder groups self-organised into two centralised subgroups. This movement could be explained by the concentration of groups and organisations interested in participating of the negotiation phase. It was found that network itself was less centralised in the agreement phase than during the negotiation phase, due to reorganisation to include the new relationships and new information sharing pathways (Chaffin et al., 2016).

The same research used node-level centrality measures (degree and betweenness centrality), identifying the shifts of power in the basin during the governance transition, and the creation of groups that could represent an opportunity for more a polycentric structure. The federal government, which was the most central node during the conflict phase, what could be expected due to its authority and mediation role, partially lost its centrality over time, opening space for new nodes and coalitions of stakeholders. "The creation of these groups also symbolised a designed increase in communication for the transparency of negotiating a vision for governance; this increase in stakeholder communication ultimately manifested as increased trust and knowledge sharing – key elements of adaptive capacity that support transitions toward adaptive governance" (Chaffin et al., 2016).

A study of the institutional network responsible for the elaboration of environmental risk management strategies in Austria reported a shift from a highly fragmented institutional framework, which represented a problem of coordination, to a centralised and low-modularity network over time, which excluded important actors from the elaboration of the Flood Risk Management Plan. The analysis indicate that although the network centralisation reduced inter-regional coordination problems, enhancing adaptability, the low modularity persisted, and improving connections between groups of actors could contribute to a better adaptive management of flood events in Austria, bringing together wider knowledge important for dealing with uncertainty and change (Ceddia et al, 2017).

Similarly, a comparative study between multi-stakeholder networks for transboundary marine governance in Tanzania and Kenya revealed strong links between stakeholders in centralised networks, but collaboration occurred basically between organizations which had established previous relations. In this case, networks of both countries improved knowledge and transmission of information, but these flows were concentrated in links of a few nodes. In addition, networks differed in the formation of their ties. While networks in Kenya were influenced by the geographical proximity of organisations, the associations in Tanzania were more likely to collaborate with institutions of the same type. Authors suggest that those differences could hinder the likelihood of valuable transboundary interactions (Tuda et al., 2019). Findings provide evidence that different social, cultural and political reasons are expected to be reflected in networks' structures, influencing adaptive management in ecosystem governance.

Formal and informal networks

Adaptive governance in social-ecological systems depend on complementary functions performed by different types of organisations. Folke et al. (2005) argue that informal organisations facilitate informations flows, contribute to span knowledge gaps and create nodes of expertise for problem-solving in ecosystem management. They explain that the lack of institutional obligations allows members of informal networks to develop alternative policies and solutions with more independence and creativity, fostering transformations in government systems (Folke et al., 2005).

In contrast, empirical research demonstrates that nodes with a formal status can also act as knowledge brokers, while "informal nodes" guarantee penetration and reach of information. A study of community farming and weather/climate information networks in southern India exemplified these interweaving roles of formal and informal networks, evidencing horizontal and vertical processes of information sharing. Local networks were classified in two types: formal (which included formalised actors supported by governmental authorities or institutions) or informal (non-institutionalised social networks). Authors conclude that linkages between formal and informal networks seems to be important for an adequate access to climate information, in support to decision-making (Nidumolu, Lim-Camacho, Gaillard, Hayman, & Howden, 2018).

A social network analysis of food and agriculture institutional policies in Santa Lucia demonstrated the effects of shifts in country's agricultural production systems from a domestic market driven model to an export banana intensification. It was observed a gradual decrease in social capital in domestic markets of the Caribbean island country, previously ruled by informal institutions. Changes were associated with reduced intra and inter community interactions, resulting in less bonding and bridging social capital. In turn it was identified an increase in so-called linking social capital, i.e. connections ruled by formal and powerful institutions related to the export market (Saint Ville, Hickey & Phillip, 2017).

Differences in the role of informal and formal structures might be explained by methodological approaches or the kind of relations under study, as papers refer to informal networks, informal nodes or informal linkages. For example, results of research with decision and policy makers' network in Great Lakes Fisherie Commission, in United States and Canada, showed that respondents share formal and informal relationships with the same organisations (Mulvaney, Lee, Höök, & Prokopy, 2015).

Conclusions

Social Network Theory has been used as a theoretical approach to research on adaptive management of social-ecological systems (SES), as the configuration of social

structures, nodes (individuals and institutions) and the types of linkages between these nodes are associated with adaptive capacity, a core issue of resilient SES. Discussions on adaptive management include other related concepts, particularly adaptive co-management (collaboration between actors) and adaptive government (institutional coordination), which depend on certain traits of individuals and institutions and their ability to build mechanisms to respond to change.

Several studies indicate that members of high-density networks are usually more likely to collaborate with each others, due to the establishment of trust and supportive relations. However, collective action depends on several other factors, including qualitative aspects of the network and their ties, and the existence of good coordination which is usually found on centralised structures. Network modularity (betweenness) is a characteristic of those networks more able to form groups, a key component for adaptive capacity in most management structures, as it fosters innovation, experimentation and access to different resources. The quality of ties in high-modularity networks and their capacity to maintain good coordination in polycentric structures is crucial for adaptive management and governance.

We discussed the role of individuals in building networks prone to adaptive management practices, and the most common metrics used to identify key nodes or stakeholders that are able to influence collective action and exchanges in the network. Scholars highlight the key role of nodes with many connections (centrality degree) or with the capacity to connect others (betweenness degree) to generate at the same time cohesive and heterogeneous relations. We also pointed out the different functions of formal and informal institutions within governance structures, in creating trustworthy relations to influence actors, in mediation and fostering innovation.

Social network analysis provides valuable tools to qualitative approaches that allow better understanding interactions between actors that affect management in different scales. This non-extensive review highlighted the most common structural features which, combined with varied analytical frameworks, contribute to the study the capacity of social-ecological systems to adapt to deal with uncertainty and change.

Contributions of authors

Thiago Sabatinelli Rodrigues: Conceptualisation, critical review, interpretation and analysis of papers, writing and final review.

Gisela Aguilar Benítez: Analysis of the results, final review.

Conflicts of interest

The authors declare no conflict of interest.

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