Wetlands
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SOCIOECONOMIC ASPECTS OF WETLANDS

Exploring Social-Ecological Complexities of Wetlands of International Importance (Ramsar Sites): the Carlos Anwandter Sanctuary (Valdivia, Chile) as a Case Study

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Abstract Complexity is an accepted characteristic of social-ecological systems. However, its analysis has been mostly theoretical with few empirical studies. Complex systems share three features: radical openness (the system cannot be understood unless an extended, global, environment is considered), radical uncertainty (emergence and non-linearity make them impossible to be fully predictable) and contextuality (no unique way to know them). Social-ecological systems listed as important under international treaties, such as wetlands within the Ramsar Convention, share these features, which can be explored using case studies. In this article, we explore the complexities derived from the 2004 ecological change (i.e. the local collapse of an emblematic bird species) in the Carlos Anwandter Sanctuary, a Chilean coastal wetland, by means of two ten-year windows (scientific publications and Internet web pages). We based our analysis on the question: what is the state of knowledge, ten years after its ecological change? Results show many answers; science has several hypotheses with low testing possibilities. Still, civil society decided that only one (a forestry company guilty of producing the change) is valid. We discuss the role of international organizations when dealing with social-ecological conflicts and identify the conundrum that can develop in response to how these are handled.

Keywords Social-ecological systems · Wetlands · Complexity · Ramsar · Post-normal science

Introduction

The analysis of complexity in coupled human-natural systems, otherwise known as social-ecological systems (SESs), has been mostly theoretical (Liu et al. 2007; Bennett et al. 2015). A literature search on complexity and SESs as "topic' terms, using Thomson Reuters Web of Knowledge, generated nearly 270 articles. Still, when the same terms were used as 'title' words, the number of articles was reduced to three (Audouin et al. 2013; Rogers et al. 2013; Vervoort et al. 2014). Thus, its empirical study is still in its infancy. One consequence of this situation is that researchers may revert to reductionism when attempting to understand the complexities of SESs (Audouin et al. 2013). Alternatively, embracing post-normal (Marín and Delgado 2013) and/or post-reductionist (Preiser 2012) approaches may help when analysing these complex systems. For example, Delgado et al. (2009) using a post-normal constructivist approach, show how social perception could be incorporated in the study of SESs using participative modelling. Jones et al. (2012) use a questionnaire to study the relationships between local perception and social capital as related to protected wetland areas in Greece. Audouin et al. (2013) propose five questions that should be considered when

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studying SESs; covering goals, boundaries, assumptions, knowledge types, needs and values. Finally, Marín and Delgado (2013), using a post-normal perspective, show how the presence of radical uncertainty influenced the way in which different social actors perceived a given social-ecological problem.

Rogers et al. (2013) propose that studies on complexity in SESs could be divided into: "case study" and "action" research, where the former is a method "for researchers to gain a better understanding of how people experience and respond to real-life situations". In this article, we describe and discuss social-ecological issues related to the ecological changes (i.e. the local collapse of a population of an emblematic bird species) that occurred during the year 2004 in the Carlos Anwandter Sanctuary (Valdivia, Chile), a wetland of international importance under the Ramsar Convention (Ramsar 2017). Our main objective is to use this case study to highlight what could be described as a wicked problem (sensu Allan 2009), related to the structure and interactions within wetlands as social-ecological systems, when analysed using two windows to observe complexity: science and society.

The Ramsar Convention on Wetlands

The International Convention on Wetlands, or Ramsar Convention, is an intergovernmental treaty that provides a framework for national action and international cooperation for the conservation and wise use of wetlands and their resources (Ramsar 2017). Currently the Convention includes 2261 sites from 169 Contracting Parties, covering a worldwide surface just over 2.15 million km^2, as wetlands of international importance (known as Ramsar sites; www.ramsar.org accessed 9 March 2017). The Contracting Parties confirmed in 2005 their vision of wetlands as social-ecological systems, with the purpose of conserving biological diversity, sustaining human life and generating ecosystem services (Ramsar 2017). However, this commitment by the Contracting Parties has not been matched by action with for example, only one third having a national wetland inventory (Finlayson 2012) which is considered a basic requirement for effective management of wetlands (Finlayson et al. 2011). Furthermore, the global decline of wetlands exceeds that found in many other ecosystems (MEA 2005; Carpenter et al. 2011). Thus, despite successful implementation in some countries (e.g. Mauerhofer et al. 2015; Lynch et al. 2016), the effectiveness of the Convention is weakened by inadequate attention being directed towards the complexity of managing wetlands as SESs (Hettiarachchi et al. 2015). Chile, a Contracting Party, has designated 13 wetlands as Ramsar sites (8 in the high Andes and 5 coastal systems) covering 3.6×10^3 km^2. The first site designated (accepted in July 1981) was the Carlos Anwandter Sanctuary, a 48 km^2 coastal wetland, and the case study for this article.

The Carlos Anwandter Sanctuary: Social-Ecological Issues

Delgado et al. (2009) have described the ecology of the Carlos Anwandter Sanctuary and its major changes during the year 2004. There is also some data on the ecological character of the wetland when it was proposed as a Ramsar Site (RSIS 2017). Succinctly, there was an increase in water turbidity (suspended solids = 5.5 mg L^{-1} in 1995 to values above 30.0 mg L^{-1} in 2004) and the collapse of the main food source (the macrophyte *Egeria densa*) of the iconic black-necked swan (*Cygnus melancoryphus*), triggering its departure from the wetland and generating a local population collapse from 8000 individuals in April 2004 to 249 in August 2005 (Delgado and Marín 2013). Several causes were proposed for these changes, which we grouped in two general hypotheses (Delgado et al. 2009, 2014):

(1) The changes were the direct consequence of illegal discharges by Planta de Celulosa Arauco Valdivia, a pulp-mill plant (property of Arauco forestry company, CELCO) located 25 km upstream, and
(2) The changes were caused by other factors not directly related to the operations of the pulp-mill plant

Although these are still valid, conflicting, hypotheses, Chilean society has chosen one. During the year 2004, Chile was actively trying to become a member of the Organization for Economic Co-operation and Development (OECD 2017) and the events developing in the Sanctuary, in terms of environmental issues, were interpreted as being a threat to successfully meeting membership requirements (Marín and Delgado 2013). For example, one of the recommendations by the OECD on its "Environmental Performance Reviews" of Chile for the period 1999–2004 was to "*survey wetlands and assure their protection through regulations and incentives*" (page 4; OECD 2005). On 25 April 2005, the Chilean government filed a lawsuit against the pulp-mill based on a study undertaken by the Universidad Austral de Chile (UACH 2005) that partly concluded that their industrial residues caused the observed changes in the wetland. On October 2006, the Carlos Anwandter Sanctuary was entered into the Montreux Record of Ramsar sites where adverse changes in ecological character have occurred, are occurring or are likely to occur (Ramsar 2017). Chile was accepted as a

member of the OECD on December 2009 (Sáez 2010). Four years later, on 27 July 2013, the Chilean press (e. g. Cox 2013; EMOL 2013) released the news that the Court of First Instance from Valdivia had ruled against the pulp-mill company. Within the decision text (page 110, original text in Spanish; Bio-Bio 2013) the judge stated:

> "*... It is clear that the Sanctuary of Nature, starting in the year 2004 suffered significant environmental changes, without having sufficiently established that it was due to natural causes, but due to the only external phenomenon, close in time, and related to human productive activities, as the start of operations of the Valdivia Plant*".

Finally, on 26 August 2013 the company released a public declaration stating its decision to accept the verdict without appeal (CELCO 2013). Thus, all complexities and uncertainties expressed in the two hypotheses were solved, from a societal perspective, by the acceptance of the verdict. In this article, we analyse the complexity of the 2004 event in the Carlos Anwandter Sanctuary and its subsequent ten-year development.

Methods

Defining the System under Study

One of the consequences of embracing a complexity approach to the study of SESs, sometimes defined as a mode 2 or post-normal approach to science, is that researchers should accept the responsibility of defining the system and its environment (Delgado and Marín 2005, 2009; Delgado et al. 2013; Audouin et al. 2013). In this case, we have defined them using a modified (Delgado et al. 2013) watershed approach (Fig. 1). Our study system, from a social-ecological point of view, corresponded to the Río Cruces watershed, including the city of Valdivia (Fig. 2); and the ecological unit the Carlos Anwandter Sanctuary, which is part of the Río Cruces wetland system (Delgado and Marín 2013). The environment was divided in two (local and extended), using a hierarchical perspective (Marín et al. 2009). The local environment is a geographic area where it is anticipated that most interactions with the system under study will occur. The extended environment is what lies beyond the local environment, where interactions still occur but less often. In both cases, under a complexity approach, they will be contextual to the problem under analysis and the same study unit will have several environments depending on the questions and the researchers who ask them. We used our previous analysis of the Carlos Anwandter Sanctuary (Delgado et al. 2009; Marín and Delgado 2013) and defined Chile and its society as the local environment. Furthermore, although the extended environment could encompass everything else (radical openness; Chu et al. 2003), as two international organizations (The Organization for Economic Co-operation and Development, OECD, and the Ramsar Convention) played important roles in the 2004 conflict (see above), we selected them as units within that environment.

Windows to Social-Ecological Complexity

Complexity can be defined as the state of being formed of many parts making something difficult to understand (see also Waltner-Toews et al. 2008; Schmitz 2010). On

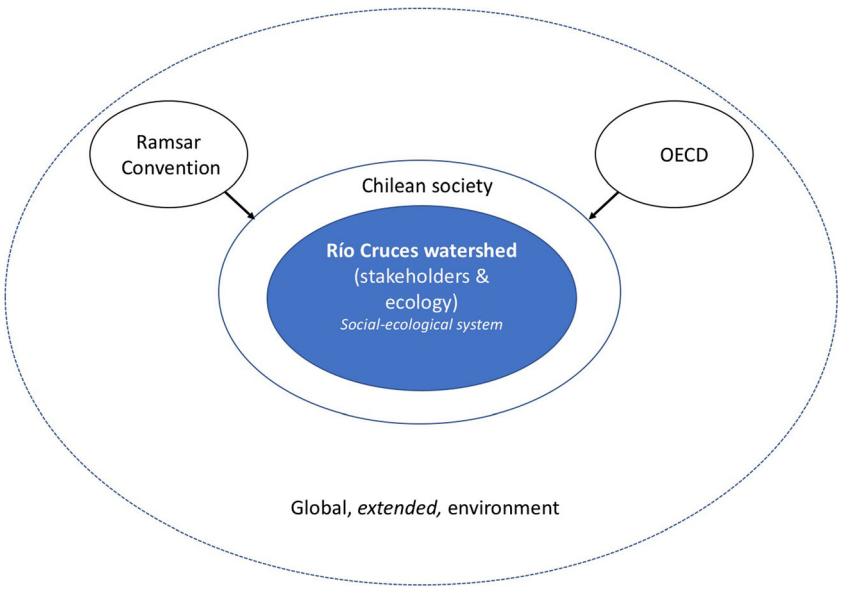

Fig. 1 Study unit (in *blue*) local (Chilean society) and extended environment for the analysis of the 2004 Carlos Anwandter Sanctuary social-ecological conflict

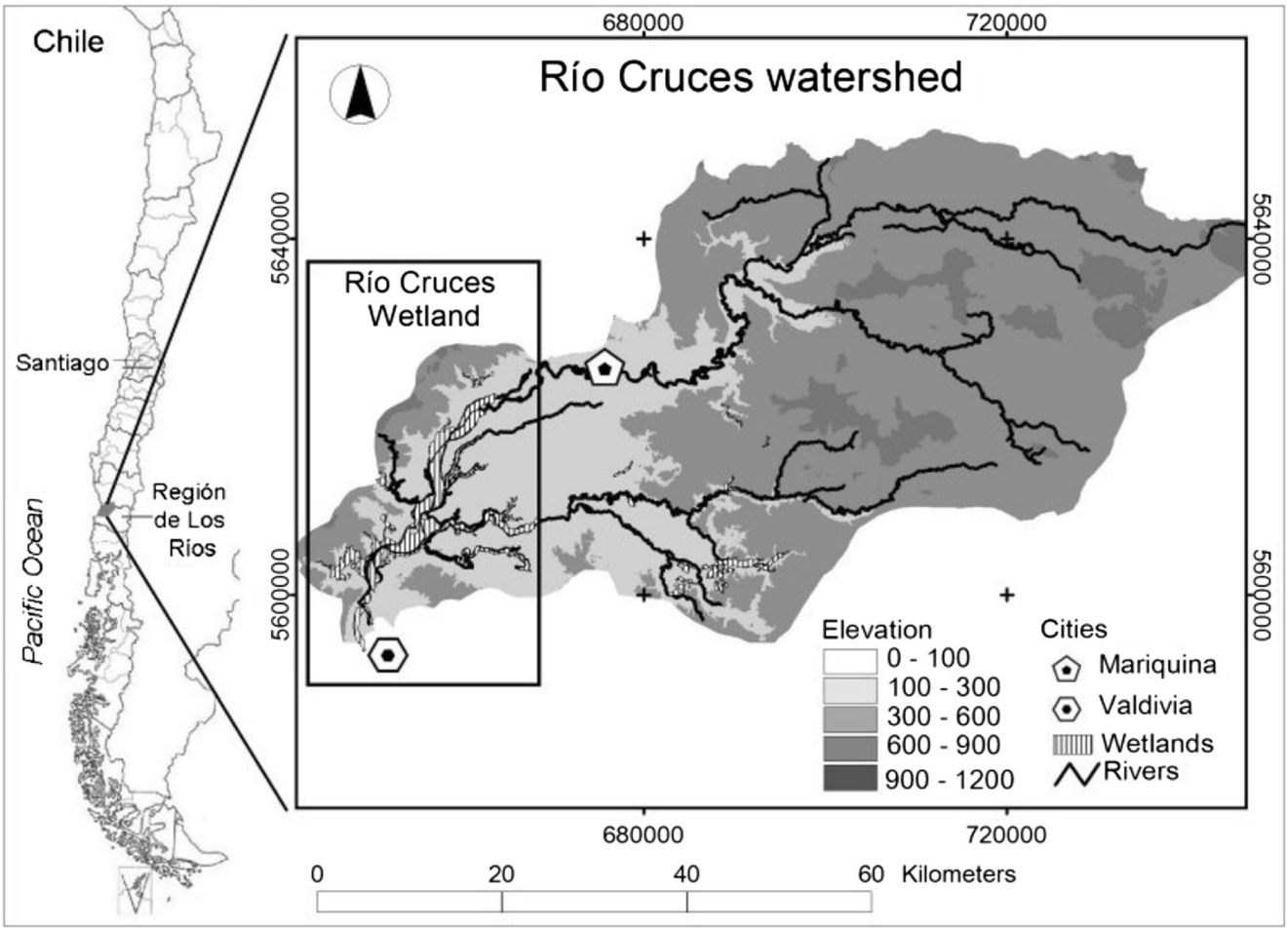

Fig. 2 Geographic location of the studied area. The large shaded polygon inside the Río Cruces wetland rectangle corresponds to the Carlos Anwandter Sanctuary

the other hand, some authors have avoided searching for an agreed definition proposing instead that complex systems share three essential features, radical openness, radical uncertainty and contextuality, that makes their control and prediction very difficult, or even impossible (Chu et al. 2003). One way to approach such complexity is to observe it from different perspectives using available windows, such as the records from the scientific literature and newspaper articles dealing with a given issue (see also Rogers et al. 2013). We analysed the complexity of the 2004 event in the Carlos Anwandter Sanctuary and its ten-year development through two windows: science and society.

The Río Cruces wetland was formed on May 22nd, 1960; it was generated as the result of the strongest earthquake recorded in the planet in recent times (9.6 on the Richter scale), which produced a 2 to 3 m subsidence of the areas surrounding the Cruces River (Marín and Delgado 2013). Consequently, there is no long-term indigenous knowledge and the main source of information about the wetland comes from recent traditional, western academic, science as described in its Ramsar Information Sheet (Ramsar 2017).

Thus, for the first window (science), we searched the scientific literature for articles published between 2004 and 2014 on the ecology of Río Cruces wetland using three databases (SCOPUS, SCIELO and ISI Web of Knowledge), resulting in 18 articles (Annex I). For the second window (society), we analysed the temporal dynamics of social communications related to this ecological change using an environmental characteristic that became associated with it: brown waters; corresponding to water in the wetland with concentrations of suspended solids above 30.0 mg L^{-1} (Delgado et al. 2014; Marín et al. 2014).

The decline of the swan population in the Carlos Anwandter Sanctuary was socially known as "*The ecological disaster of the Río Cruces Sanctuary*". This term was widely spread through mass media and articles published in scientific and social journals (Sepúlveda and Bettati 2005; Delgado

et al. 2009; Marín and Delgado 2013). For example, the Chilean national newspaper "La Nación" in an article written on February 21, 2005 stated: "*However, the brown waters that identifies the pollution of Río Cruces have moved so rapidly in the last months with the tidal changes, that it is invading the traditional Calle Calle River*" (La Nación 2005). Furthermore, the actual number of local dead swans was small (< 200 in the period 2004/2005), spread over a large area and with most swans migrating to other locations along the Chilean coast (Lopetegui et al. 2007). Consequently, we chose the allegedly, highly visible, pressure variable (brown waters; Marín and Delgado 2013) to study the social perception of changes within the wetland through the Internet, using "*mancha café*" *[brown water] AND* "*Río Cruces*" as searching text. We found 158 web pages, but after cleaning for missing links and erroneous content, the total number of web pages was reduced to 56, containing information and comments on brown wetland waters.

Results

The Science Window

The literature search revealed eight different explanations for the 2004 event (Table 1); five involving mechanisms other than pulp-mill discharges (H1–3, H7–8) and the other three linking the change directly to its operation (H4–6). Still, a careful analysis shows that each introduced a different causal factor, with low testing likelihood given the lack of comparable historical data (see below). Only some of them have been falsified (H2, H3 & H6); the others should still be considered as valid, conflicting, scientific explanations.

One requirement of listing a wetland under the Ramsar Convention is to have scientific information about its ecological character (RSIS 2017). In the case of the Sanctuary, the only continuous (time series) available data, prior to 2004, were monthly waterbirds counts that had been conducted since 1985 (Delgado and Marín 2013). Furthermore, the amount of information provided for the site and submitted to the Ramsar Convention in 1992 and 1998 as a description of the ecological condition of the wetland is sparse (RSIS 2017). For example, the 1992 Ramsar file for this wetland does not provide nutrient values, except for stating that they are low and that sediments are high in nitrogen. On the other hand, the 1998 file shows that total phosphorus was between 7.18 and 8.9 $\mu g\ L^{-1}$ and total nitrogen between 78.6 and 99.6 $\mu g\ L^{-1}$. If we compare those values with the OECD criteria for trophic status (Marín et al. 2014), the wetland was oligotrophic when proposed as a Ramsar site. The current ecological condition of the wetland is characterized by water turbidity intermediate (between 10.0 and 20.0 $mg\ L^{-1}$ for suspended solids) between the turbid condition that existed in 2004 (above 30.0 $mg\ L^{-1}$ for suspended solids) and the clear condition (5.5 $mg\ L^{-1}$ for suspended solids) that occurred beforehand (Delgado and Marín 2013; Marín et al. 2014; RSIS 2017). Bird numbers (8056), up to April 2016, have increased since early 2011, reaching the maximum levels pre-2004 (CONAF 2016). However, the wetland's trophic status (using the criteria for nutrients, chlorophyll and water transparency of the OECD; Marín et al. 2014) is between eutrophic and hypertrophic generating considerable uncertainty and a risk of returning to turbid conditions. Furthermore, current ecological theory (e.

Table 1 Hypotheses about the origin of the ecological changes of the Río Cruces wetland ecosystem during the year 2004

Hypothesis	Mechanism	Reference
Water flood (H1)	Flooding eroded *E. densa* roots	SAG (2005)
Salinity (H2)	An unusual increase in salinity reached the tolerance of *E. densa*	SAG (2005)
Ultraviolet radiation (H3)	A UV radiation increase killed *E. densa* in shallow waters	Ramírez et al. (2006)
Iron poisoning (H4)	*E. densa* disappeared due to iron poisoning	UACH (2005)
Aluminium sulphate shading (H5)	Slime generated by the interaction of aluminium sulphate and organic matter affected the photosynthesis rates of *E. densa*	UACH (2005)
Aluminium sulphate-CO_2 (H6)	The aluminium sulphate decreased the CO_2 concentration within the wetland, affecting the photosynthesis of *E. densa*	Mulsow and Grandjean (2006)
Drawdown (H7)	A climatic anomaly during 2004 produced low water levels killing *E. densa* by desiccation.	Marín et al. (2009)
Land use changes (H8)	Land use changes in the watershed (intensification of forestry including clear cut practices) increased the concentration of suspended solids affecting the photosynthesis of *E. densa*	Delgado et al. (2014);

g. Ibelings et al. 2007; Schmitz 2010) does not provide clear guidance on what to expect in the future (Marín et al. 2014).

How much have we advanced in our ecological knowledge of the Sanctuary since 2004? The result of our inquiry is available in Annex I. When articles were sorted by financial institution, leaving aside those without information, the Chilean government have funded nearly a third (28%), the Pulp Mill Company another third (36%) and one third being funded by grant funding institutions (36%). All articles financed by the pulp mill company show that the available information is either insufficient to establish cause-effect relationships or they describe new data discrediting the "industry guilty" hypotheses. On the other hand, articles financed by the Chilean government either assume a relationship between the pulp mill operations and ecological changes during 2004 (Lopetegui et al. 2007; Lagos et al. 2008), propose new hypothesis (Marín et al. 2009) or review existing information (Yarrow et al. 2009). Finally, articles financed by grant agencies explore new approaches or analyse new ecological data (Schaefer and Einax 2010; Delgado and Marín 2013; Palma-Fleming et al. 2013; Delgado et al. 2014). Thus, after ten years of scientific inquiry the complexity/uncertainty of the 2004 event has not decreased. This condition can in fact be described as post-normal (several legitimate perspectives; Marín and Delgado 2013), where contextuality in the available knowledge (in the sense of Chu et al. 2003) plays an important role.

The Society Window

On 23 October 2004, a local online newspaper (*El Austral de Valdivia*) included a small article entitled "*Alert due to dying of swans*" (CEACHILE 2012). The article, showing a photograph of a dead swan being held by law enforcement agents, described how black-necked swans were dying near the wetland. Although this can be considered as the beginning of the Sanctuary social-ecological conflict, some authors have proposed that tension on environmental issues among the pulp mill company, governmental organizations and social actors existed previously (Sepúlveda and Bettati 2005). Still, two months after this first broadcast, newspaper articles on brown waters and swans started appearing, fading away by January 2008 (Fig. 3). It is worth noting that the re-appearance of this issue on December 2010 coincided with the travel of the Chilean President to the Valdivia area. We divided the conflict, from the standpoint of social communications,

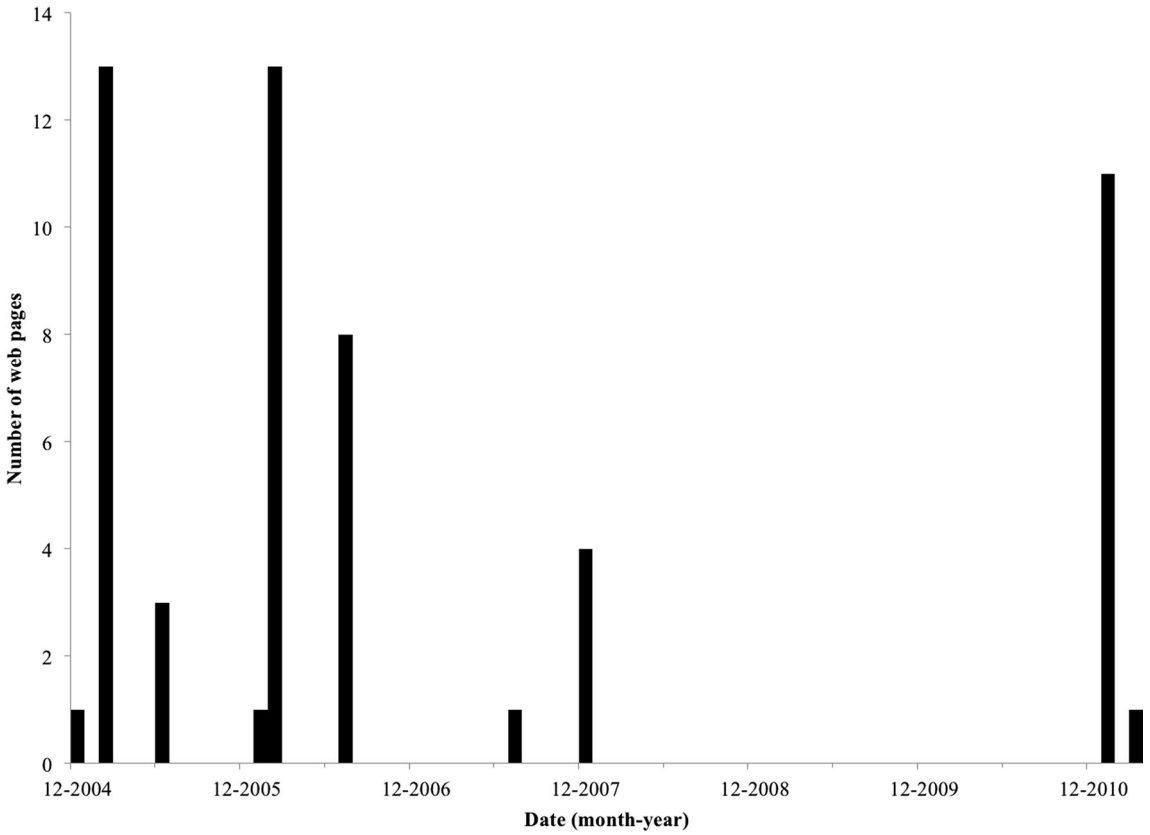

Fig. 3 Time sequence of Internet news on brown waters (mancha café) and Río Cruces during the period December 2004 – January 2011. No news was found prior to December 2004 or after January 2011 until July 2013 (see text for further details)

into three periods. (I) *2004–2008*, characterized by high media exposure; (II) *2008-July 2013*, when almost no news was published; and (III) *July 2013 up to the present,* characterized by the Court ruling and the sporadic appearance of wetland issues on the Internet, mostly related to the consequences (legal and social) of such ruling (CCS 2016a). The in-depth analysis of all web pages showed that most of them (40) were copies of 16 original sources, mainly (67%) from highly educated local people (e.g. university professors, medical doctors, Chilean Senate members) that blamed the pulp-mill company for the changes in the wetland during 2004. The result was the generation of a single social description about the 2004 event and its causes, producing a powerful narrative (in the sense of Kay 2000). This narrative, supported by governmental organizations (Marín and Delgado 2013), is still present in the local society (Opazo 2014; CCS 2016a) and it was the main argument in the 2013 Court ruling.

Discussion

What we have illustrated - the 10-year coexistence of conflicting explanations over a given issue - occurs routinely in science (Geymonat 2006). In fact, it is fair to state that scientists have grown to accept it as a characteristic of our work. However, when looked at from a societal window, the situation changes dramatically. Societies require closure on issues such as the catastrophic ecological change in a wetland; for example, the identification of a cause and responsibilities (e.g. the lawsuit of the Chilean Government against CELCO). Under these conditions, we enter the domain of post-normal science where: facts are uncertain, values in dispute, stakes high, multiplicity of legitimate perspectives and decisions urgent (Ravetz 2006; Frame and Brown 2008; Marín and Delgado 2013). In the analysed case, the solution was simple: all parties involved accepted the verdict of the court. This facilitated social closure, reducing complexity to a minimum. This type of processes, and the analysis of the society window, can be affected by the evolving nature of the internet. For example, information from the Chilean Under Secretariat for Telecommunications shows that between 2010 and 2016 internet penetration in Chile increased from 15.1% to 84.1% (EMOL 2016). Although it could be argued that such a drastic change could have played a role in the information available to the public, it does not explain the sudden disappearance after December 2007 (Fig. 3). Furthermore, Marín and Delgado (2013) show that 1284 press articles were published in the period 2004–2008. Consequently, society had plenty of information during the period 2004–2008 although most of them did not come directly from science (see also Annex I).

One of the requirements of the Ramsar Convention is that Contracting Parties (national governments) should submit standard national reports, explaining their actions regarding their listed sites. Section 3 of the national report relates to indicators, including questions on the objective of "wise use of wetlands". Two questions associated with that objective deal with the restoration of wetlands. Chile as contracting party submitted a report during 2015 (Ramsar 2015), where it states that it has defined the Carlos Anwandter Sanctuary as a priority site for restoration, further stating that there are ongoing restoration/rehabilitation projects. However, ecological restoration requires a reference ecosystem or a conceptual model to set goals and to plan a restoration project, and later for its evaluation (SER 2004). In the case of the Carlos Anwandter Sanctuary, the only "reference ecosystem" seems to be a loosely defined "pre-2004" condition (Cox 2013). Under the provisions of the Ramsar Convention the default position is that the ecological condition that was described when the site was listed as internationally important would be restored (Finlayson et al. 2011). However, there is increasing doubt that prescriptions such as this are feasible within the context of global change (Kopf et al. 2015; Gell et al. 2016). Furthermore, the verdict against the pulp-mill company included a statement regarding the current ecological condition of the wetland as "*nature has done its part*" (page 160; Bio-Bio 2013), rejecting restoration as a requirement and demanding only a diagnosis (e. g. CCS 2016a) and integrated monitoring among the five actions ordered by the judge (page 162; Bio-Bio 2013). These differences among the Ramsar Convention, the Chilean Government and the Chilean Judicial System can be interpreted as disconnections or as the inevitable consequences of social-ecological complexities (e.g. Hettiarachchi et al. 2015) and the post-modern condition of science-policy interfaces (Guimarães Pereira et al. 2006; Marín and Delgado 2013). Indeed, Rogers et al. (2013) propose that when looking at social-ecological systems from a complexity perspective: (1) scientific objectivity becomes largely a myth, (2) the use of the term "problem solving" is inadequate, and (3) a reductive-reductionist approach will disfigure our perceptions of reality. As stated by Ravetz (2006): "The more narrowly trained researchers engage in post-normal situations, the greater will be their distress".

Thus, what is the state of the Carlos Anwandter Sanctuary, ten years after its ecological change? That will depend on who answers the question. From the point of view of Chile, as a Contracting Party to the Ramsar Convention, it is a social-ecological system where restoration actions (whatever they are) are taking place, to enable the site to be removed from the Montreux Record of Ramsar sites that have undergone adverse change in ecological character (Ramsar 2015). From the perspective of the Chilean Judicial System, it is a closed case where the judge, by means of formal legal truth (Summers 1999), was convinced beyond reasonable doubt

and ruled that in the absence of other evidence, the pulp-mill was responsible for the 2004 environmental change. From the perspective of those who participated in the judicial case it is also settled, since all accepted the verdict of the court without appeal. For the Chilean society at large, a forgotten issue? For the local society, (i.e. social actors to the conflict) it represents an ecologically and environmentally deteriorated wetland (due to the pulp-mill plant). Where information is lacking, there is apprehension by political authorities although they perceive some recovery but with large uncertainties for the future (CH_RC 2016). Science still has several hypotheses (Table 1); yet, there seems to be agreement on certain issues (Delgado and Marín 2013; CCS 2016b):

(1) The current trophic state is much higher (eutrophic to hypertrophic) than that when the wetland was accepted as a Ramsar site.
(2) The local population of black-necked swans started increasing during 2011, reaching 8056 individuals by April 2016 after six years of population values below 1000 individuals (CONAF 2016).
(3) There has been a concurrent increase in swan habitat and food (e.g. macrophytes).
(4) There are uncertainties about (Marín et al. 2014) and/or threats (CCS 2016b) to the future ecological character of the wetland, specifically for the population of black-necked swans.

One of the results of embracing a complexity approach to the study of social-ecological systems, as we have discussed it above, is the condition of uncertainty, mostly generated by their non-linear dynamics (Audouin et al. 2013; Rogers et al. 2013; Vervoort et al. 2014). Uncertainty is also in the language used by the Ramsar Convention, but as something that can be "solved" (e.g. Hesselink et al. 2006; Horwitz et al. 2012). However, uncertainty as related to social-ecological systems is radical and it cannot be solved, only accepted (Marín and Delgado 2013). Indeed, this proposal can be rephrased using the words and concepts discussed by Waltner-Toews et al. (2008) as: It is necessary to install, both within scientists and managers as well, that there will always be views and perceptions about a given social-ecological system that will generate different options, all beset with uncertainties. Furthermore, consensus may be an important mechanism for political agreements within international treaties such as the Ramsar Convention, but it does not play a role in science (Nelson 2016). Scientists do not have to reach a consensus about the 2004 event in the Carlos Anwandter Sanctuary. Rather, we should accept these processes from a post-normal perspective, where all perceptions are legitimate. In this condition, social actors related to a given social-ecological system (scientists included) must have, at least, the opportunity to show and discuss their views with all others. One way to accomplish this is by developing conceptual, participative, models (Van den Belt 2004; Delgado et al. 2009; Capra and Luisi 2014). Then, we should generate as many conceptual models of SESs as opinions, and use them as narratives so all interested parties (international treaties, governments, NGOs, social groups) may explicitly see what other people are thinking about the system to be managed. Such a strategy is not necessarily simple, and a great deal of cooperation will be necessary especially if positions are in conflict. However, since attempts to reduce complexity are likely to generate only conundrums, we will have to embrace it, or face the ongoing difficulty, possibly including social discord and scientific dissonance, of dealing with a conundrum.

Thus, while society may have accepted closure regarding the ecological changes at the wetland following the court decision, wetland managers and the national Administrative Authority for implementing the Ramsar Convention in Chile still has an obligation to monitor the wetland and report on further changes. Consequently, especially given the uncertainty about the causes of the changes, and whether macrophytes would re-establish and the swans return, the Authority would be expected to collect further information for management purposes, including possible remediation or restoration of the wetland, and to assess this as part of an ongoing management planning process, making such information available to local communities and the scientific sector with an interest in the wetland. In this regard, governments should implement and maintain relevant monitoring and assessment programs, as recommended by the Ramsar Convention, to ensure the wise use of the wetland (Finlayson et al. 2011) and to report any changes to the Convention (Finlayson 1996a) using relevant hypothesis-based collection of new information (Finlayson 1996b). Furthermore, the Convention, as part of the management planning for wetlands, encourages the full participation of local communities and the use of adaptive approaches (Ramsar 2010) to maintain their ecological character. The creation of the Scientific and Social Council for the Río Cruces wetland (CCS 2016a), can indeed be a step in this direction. However, the Convention's Scientific and Technical Review Panel has previously been requested to consider ways of determining limits of acceptable change in wetlands, but has not hitherto been provided with the means to do this (Finlayson et al. 2017); the use of early warning signals that enabled future changes to be detected at the earliest possible time would greatly improve the capability of managers to both inform the wider society and to make decisions, including those for management and those for more intensive investigations.

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Annex I

Table 2 Articles published between 2004 and 2014 on the ecology of the Río Cruces wetland ecosystem

Reference	Main issues
Delgado et al. (2014)	Generate a conceptual ecosystem/watershed to explain the changes on the basis of land use modifications
Delgado and Marín (2013)	Changes in the habitat area of black necked swans had started before the year 2004
Gonzalez and Farina (2013)	Not enough information to infer cause-effect relationships
Hauenstein (2004)	Speculate about the causes of swan drastic reduction citing UACH (2005)
Lagos et al. (2008)	Increase in water turbidity and decrease in *E. densa* coverage started in 2004, along with decrease in river flow. They conclude that changes "could be related to the new pulp mill"
Lopetegui et al. (2007)	Authors assume that excess aluminum generated by the pulp mill contributed to iron and heavy metals precipitation, killing *E. densa*
Marín et al. (2009)	A Climatic event, absence of precipitations in May 2004, reduced water flows killing *E. densa* through desiccation.
Marín et al. (2014))	Current ecological condition of the wetland is between eutrophic and hypereutrophic, and the ecological regime intermediate between clear and turbid waters
Palma et al. (2013a)	Falsify the hypothesis of the effect of chlorate on *E. densa,* showing that the macrophyte tolerates high concentrations.
Palma et al. (2013b)	Describe experiments on the effect of desiccation and chlorate exposure to *E. densa*. Authors conclude that the first is the major negative condition for the macrophyte
Palma-Fleming et al. (2013)	Authors propose α-pinene monoterpene as tracer of pulp mill liquids in the wetland
Pinochet et al. (2005)	Authors conclude that high concentrations of iron could be the cause of the decrease of *E. densa*
Ramírez et al. (2006)	Authors hypothesize the effect of UV-B radiation as a factor for the disappearance of *E. densa*
Risk et al. (2010)	Authors analyse trace metals in bivalve shells from the wetland, concluding that there is no evidence of a chemical spill in 2004.
San Martín et al. (2010)	Authors conclude that UV radiation is not the cause of *E. densa* mortality, but that intensity of solar radiation reduces chlorophyll content
Schaefer and Einax (2010)	Authors conduct a chemical analysis of water and sediment samples concluding that the pulp mill sewage is not significantly polluted to prove a negative influence on the ecosystem
Schwarz et al. (2012)	Authors analyse the wetland sediments capacity to reduce chlorate to chloride and conclude that sediments both in Río Cruces as in other wetlands of the region have this capacity regardless of the presence of a cellulose plant
Yarrow et al. (2009)	Authors review the biology of *E. densa* cautioning against the idea of a highly competitive invader

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