Marín, A., S. Gelcich, and J. Castilla. 2014. Ecosystem services and abrupt transformations in a coastal wetland social-ecological system: Tubul-Raqui after the 2010 earthquake in Chile. *Ecology and Society* **19**(1): 22. http://dx.doi.org/10.5751/ES-05633-190122

Research

Ecosystem Services and Abrupt Transformations in a Coastal Wetland Social-Ecological System: Tubul-Raqui after the 2010 Earthquake in Chile

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ABSTRACT. Natural disasters can trigger sudden transformations and move ecosystems to different states where the provision of ecosystem services is altered. These changes in ecosystem services affect local communities' well-being and challenge users' adaptation capacities. We used the ecosystem services framework to understand the impacts of abrupt transformations, in a coastal wetland, associated to a ~ 1.6 meter coseismic uplift after an 8.8 magnitude earthquake in Chile. Using mixed methods we (1) identified and prioritized ecosystem services from Tubul-Raqui wetland; (2) assessed conditions of services and human well-being before and after the earthquake; (3) investigated postcatastrophe human adaptations and responses; and (4) explored users' interests and visions about possible future social-ecological pathways. Results show spatially diversified effects of the uplift on ecosystem services, both negative and positive, representing threats and opportunities for different user groups around the wetland. The total loss of the cultivated seaweed "pelillo" is associated with the most manifest reduction in perceptions of well-being among coastal users. Adaptive capacities triggered by pre-existing livelihood portfolios generated intensification in the exploitation of less impacted or enhanced ecosystem services which could be reducing resilience. Results show that two years after the transformation there is little attempt to create untried, new beginnings in the Tubul-Raqui wetland from which user groups could evolve to a more innovative livelihood and resource management system after the shift. Although visions about the future are not homogeneous among users, common interests regarding the conservation of key services are shared. The analysis of abrupt transformations through an ecosystem services approach provides a powerful framework for the study of environmental change and associated impacts on local communities.

Key Words: *adaptation; Millennium Ecosystem Assessment; natural disasters; perceptions; transformations; well-being*

INTRODUCTION

Growing concern about global environmental change and associated impacts on nature and humans has increased the interest in studying change and disturbance, and the capacity of ecological and social systems to adapt to variable and uncertain conditions (Redclift 1992, Scheffer et al. 2001, Folke et al. 2004, Scheffer 2009). A number of studies have highlighted the need to focus on abrupt, unpredictable, and irreversible ecosystem shifts and transformations (Walker et al. 2004, Barnosky et al. 2012). These can be triggered by major external impacts such as natural disasters and have historically resulted in severe shocks and transformations to societies (Tainter 1988, Diamond 2004). When faced with abrupt transformations, human preparedness is unlikely and adaptability is critically tested. Therefore, abrupt environmental changes triggered by natural disaster can represent unique learning opportunities on social responses to unknown, upcoming global environmental changes.

Ecosystem services (ES) are the multiple benefits people obtain from nature (MA 2003, 2005). Regime shifts and abrupt transformations can alter the capacity of ecosystems to provide the services sustaining human well-being (Carpenter et al. 2006). The consequences of environmental change can be more or less desirable for resource-reliant communities (Folke et al. 2004), depending on the resulting conditions and postdisturbance management options and decisions. Future opportunities to sustain ES and human well-being are highly related to the capacity of the environment, social actors, and governance institutions to cope with, adapt to, or transform when faced with change and uncertainty. Adaptability refers to the capacity of social actors to cope with, manage, or adjust to change and to positively influence the resilience of the whole system (Walker et al. 2004); adaptations can be anticipatory or reactive, autonomous or planned actions (Smit and Wandel 2006). Transformability is the capacity to create a fundamentally new system when ecological, economic, or social conditions make the existing system nonviable (Walker et al. 2004); transformational change can be unavoidable in contexts with high social vulnerability and large environmental risks (Kates et al. 2012).

The ES framework developed by the Millennium Ecosystem Assessment is a conceptual model aimed at understanding the consequences of ecosystem change for human well-being and to inform decision-making processes for sustainability (Carpenter et al. 2006, 2009, 2012). This framework has been applied in numerous studies to assess social-ecological conditions at a given moment in the history of a place where gradual changes occur (Raudsepp-Hearne et al. 2010, Palomo et al. 2011, Tuvendal and Elmqvist 2011). However, few studies have used the ES framework to assess change after abrupt transformations in social-ecological systems (Troell et al. 2005) related to natural disasters.

Tubul-Raqui (TR), in the Gulf of Arauco, Chile, has been described as one of the major coastal wetlands of Chile and of the Western South American coast (CONAMA 2003, Valdovinos et al. 2010). TR social and ecological importance is associated with its biodiversity and with the provision of multiple ES supporting local and traditional livelihoods (Fig. 1A). An abrupt transformation occurred on 27 February 2010 by the world's sixth largest earthquake ever recorded (known in Chile as 27F), associated with a ~ 1.6-meter coseismic coastal uplift in and around the Gulf of Arauco and a tsunami (Fig 1B-D). The uplift

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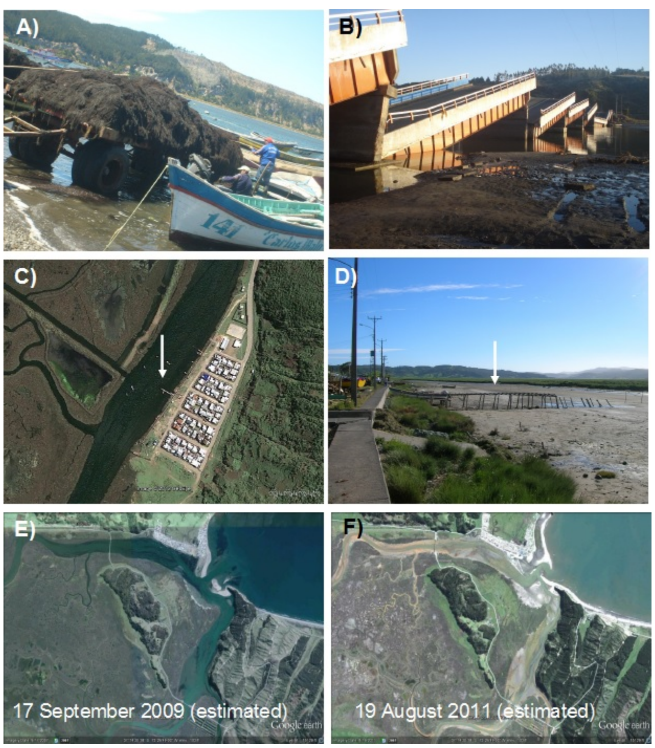
altered the hydrological balance, drying most channels and reducing salt-freshwater interaction and fundamental conditions of the wetland. The 2010 earthquake and tsunami abruptly modified ecosystems and changed the stability of the social-ecological system (Castilla et al. 2010, Valdovinos et al. 2010, Vargas et al. 2011). This abrupt shift in conditions and the uncertain future of the TR wetland provide, as a natural experiment, a unique opportunity to operationalize the ES framework, to understand human reliance on ES, and to draw lessons of social-ecological feedbacks and adaptation in the context of transformations.

Fig. 1. A) Traditional extraction of “pelillo” (*Gracilaria* sp.) in Tubul before the 2010 earthquake (courtesy of Teodoro Leal, president of the A.G. fisher organization); B) The Tubul bridge right after the 8.8 MW 2010 earthquake (courtesy of Patricio Manríquez); C) Google Earth image from Las Peñas on the Estero Las Peñas in 2009 (the arrow points at the dock and moored boats); D) Las Peñas after February 2010 earthquake (the arrow marks the useless dock and boat lying on the dried bottom of the river); E) Google Earth image from the river mouth before the 2010 earthquake (the date provided by Google Earth is estimated and the exact hour is unknown); F) Google Earth image showing redish and dried river beds after the 2010 earthquake (the date provided by Google Earth is estimated and the exact hour is unknown).



In this study we aim to investigate the effects of an abrupt transformation in the TR coastal wetland social-ecological system and to explore future social-ecological pathways. The research relies on users’ experiences, observations, and visions about the TR ecosystem and its services. The main questions posed by the study include: How do abrupt transformations affect ES and human well-being at the local scale?; How do people respond and adapt to abrupt changes?; How can this information provide insights for the management and conservation of the altered social-ecological system? To respond to these questions we: (1) identify and prioritize ES from TR wetland; (2) assess conditions of services and human well-being before and after the earthquake; (3) investigate postcatastrophe human adaptations and responses; (4) explore users’ interests and visions about possible future social-ecological pathways after the abrupt transformation.

RESEARCH SETTING: THE TUBUL-RAQUI SOCIAL-ECOLOGICAL SYSTEM

Tubul-Raqui before the 27F abrupt transformation

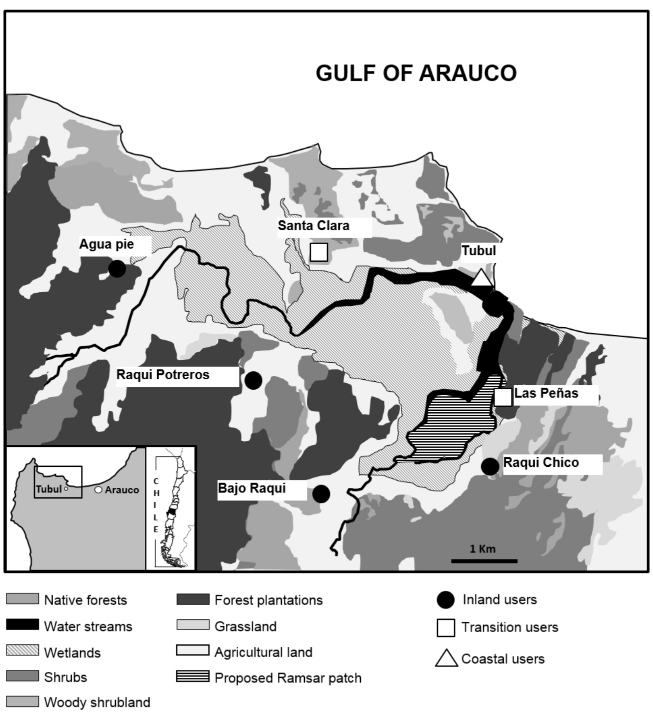
Tubul-Raqui is a coastal wetland located in the Golfo de Arauco (37°13’S-73°26’O), 71 km south from Concepción (Fig. 2). The wetland is an estuary and marsh formed by the confluence of three streams: Río Tubul, Río Raqui, and Estero Las Peñas. The whole basin encompasses 26,100 ha. The wetland itself is a coastal plain of 2600 ha, of which 190 ha traditionally represented surface water bodies. Diverse landscapes and productive habitats characterize this rich and complex ecological system (CONAMA 2003, Centro de Ciencias Ambientales EULA 2008, Valdovinos et al. 2010). Like most salt marshes, TR exhibits high rates of primary productivity due to the inflow and mix of nutrients and organics from surface and/or tidal water, determining favorable conditions for biodiversity. The wetland provides habitat and shelter to 83 bird species, including 29 endangered species and a number of migratory species (Carrasco-Lagos 2003). Also micromammals (4), reptiles (6), amphibians (1) dwell within the area (Vergara et al. 2008). Because of its richness, the TR wetland was declared a Chilean priority site under the National Strategy for Biodiversity Conservation (CONAMA 2003, Centro de Ciencias Ambientales EULA 2008).

Three ecotypes were identified within the wetland before the uplift in an unpublished report by Centro de Ecología Aplicada: (1) tidal salt marshes, near the mouth with 5 to 6 km marine influence and saltwater intrusion in Río Tubul (Alveal 1988, Werlinger and Alveal 1988); (2) an intermediate transition zone with infiltration wetlands, temporary lagoons, and canals, and dominated by salt meadows covered by *Spartina densiflora* and *Sarcocornia fruticosa* (Stuardo et al. 1993); (3) and freshwater marshes and runoffs upstream the Tubul and Raqui rivers and near the hills. Based on salinity gradients, authors have referred to these three sectors as “marine,” “ecotonal,” and “freshwater” zones (Stuardo et al. 1993, Carrasco-Lagos 2003).

Estimated human population living in the study area is 2683 inhabitants. Before the uplift more than half of them were below the poverty line (Valdovinos et al. 2010). Nearly 200 people in the area belong to indigenous ethnic groups. Most of the population lives in two rural fisher villages: Tubul (75%) and Las Peñas (12%) and the rest in smaller locations. Their economy has relied mostly on the intensive exploitation of the seaweed “pelillo” from the wetland (*Gracilaria* sp.; Alveal 1988, Werlinger and Alveal 1988; Fig. 1A). Taking advantage of the favorable estuary water composition (mix of salt and fresh water) and shallow depth, organized seaweed gatherers of the Asociación Gremial de Tubul

(A.G.) reintroduced in the 1990s the overexploited pelillo species, applied for a private aquaculture concession over 212 ha along the three rivers, and learned how to manage the valuable agar-producing resource (Alveal 1988). The A.G. is the largest artisanal fisher organization in the area with more than 650 members. In total, approximately 1500 people depended on the activity of this organization. Between 2003 and 2009, A.G.'s average annual pelillo exploitation was 1500 metric tons, accounting for more than US$560,000 annual revenues. In addition, local fishers and hookah-divers exploit natural banks of mollusk species from the Arauco Gulf near the TR mouth. Tubul is the regional main landing site of taquilla (*Mulinia edulis*), huepo (*Ensis macha*), and navajuela (*Tagelus dombeii*), with annual average production of 3100, 2600, and 2200 metric tons between 2000 and 2009, respectively (SERNAPESCA 2012).

Fig. 2. The Arauco Peninsula and the Tubul-Raqui wetland; grey-scale patches show land use before the 2010 earthquake (adapted from Centro de Ciencias Ambientales EULA 2008); shapes mark the studied locations and identify the three user groups defined for the analysis: triangle = coastal; squares = transition; circles = inland. Note that despite the relative closeness between Las Peñas and Raqui Chico, the former is in the wetland plain and the latter is on a surrounding hill. The black hatch wetland patch is the area proposed as a Ramsar site, in addition to the river streams.



Upstream, in the inner part of the wetland, local users have traditionally developed agriculture and cattle raising in grasslands and floodplains near the hills. An estimate of 400 people and approximately 80 small- and medium-scale private owners inhabit this scattered area. Their production is mostly oriented to self-consumption, to the local market, and more recently to the produce of artisan cheese. Recent state-funded irrigation and drainage projects have sought to increase productive land in the wetland margins and the availability of fodder for livestock. In the surrounding hills, intensive *Pinus radiata* and *Eucalyptus globulus* plantations have replaced native forests since the early 1990s (Valdovinos et al. 2010). Nowadays, approximately 50% of the basin is covered by small and large-scale private plantations (CONAMA 2008). As a result, only remnants of native forests exist, either as obligatory protection zones within plantations or as scattered small patches. More recently, small areas of *Eucalyptus globulus* have been planted by local owners inside the wetland using drainage systems. In addition, three wind farm projects within the basin near the wetland are under study, responding to an increased national energy demand.

In 2008, driven by conservation interests, the Regional Ministry Secretariat for the Environment conformed a working table known as TR Wetland Conservation Board (WCB, Mesa de Trabajo para la Conservación del Humedal TR). Various actors were engaged to discuss and implement sustainable use and conservation initiatives: public agencies with jurisdiction over the environment and natural resources, the Arauco Municipality, the A.G., other fisher organizations, indigenous communities, private and corporate landowners, and regional universities. The WCB established a hunting moratorium for 30 years over 7822 ha including the wetland. In 2008 the National Assets Ministry established conservation purposes for 350 state-owned hectares inside the wetland. Later, the Secretariat, with the support of the WCB, initiated the process to a Ramsar site declaration (CONAMA 2008). The proposal included the state-owned property and the 212 ha aquaculture concession administered by the A.G. along the rivers, accounting for 22% of the wetland (see Fig. 2). In January 2010 a participatory management plan for TR wetland conservation was completed, including commitments of most relevant actors (CONAMA-INGAM 2010). This study included the participation of some of these actors, namely local users of ecosystem services and their organizations.

Tubul-Raqui after the 27F abrupt transformation

On 27 February 2010, a magnitude 8.8 earthquake, the sixth largest instrumentally recorded, struck the central-south zone of Chile. Major tsunami waves hit the coast devastating coastal cities and fishing villages along 600 km of coastline (Marín et al. 2010). Housing, vessels, and infrastructure of Tubul were severely impacted by the tsunami, with peaked wave run-up of 8.40 m and inundation of more than 430 m (Fritz et al. 2011). In the wetland, tsunami waves penetrated up to 3 km, carrying large amounts of sand that was deposited over marshes and meadows. Along with the earthquake, a coastal uplift occurred leading to permanent changes in the hydrological regime of the wetland: the ground level was raised 1.6 m on average in most of the area (Fritz et al. 2011); the level and width of the sediment bar in the mouth increased; the overall phreatic level in the wetland increased (Fig. 1F). The salt and freshwater interaction after 27F was dramatically reduced, happening only during high tide and over a limited area (MMA-Centro de Ecología Aplicada 2010) only along approximately 1 - 2 km upstream of the river mouth. Valdovinos and coauthors (2010) reported the total drying of hard bottom habitats as a consequence of the uplift, leading to the total loss of aquatic fauna, e.g., the bryozoa *Conopeum* sp., the amphipoda *Paracorophium hartmannorum,* and the polychaete *Prionospio Minuspio patagonica,* which was replaced in the midterm by terrestrial invertebrates. Also, banks of economically important bivalves, such as *Tagelus dombeii* totally disappeared from soft bottom habitats in the wetland. Regarding wetland flora, *Spartina densiflora,* the keystone and so-called bioengineer species, proved to be tolerant to the changes, preventing further physical, chemical, and biological perturbations in TR.

With regard to economic activities in the area after 27F, available data indicated important changes particularly in coastal areas. Pelillo algae, which was one of the main economically important species, totally disappeared from the system, and as a consequence landings dropped to zero (SERNAPESCA 2012). Unlike pelillo, average annual landings of marine bivalves (taquilla, huepo, and navajuela) maintained stable at around 5500 metric tons after the uplift (SERNAPESCA 2012). These are similar values to those before the 27F abrupt transformation, however, anecdotal information describes consistent unregulated and illegal landings after the uplift. In addition, enforcement has become more flexible to the extent that the current dominant discourse is that bivalve mollusk landings have increased significantly but mainly through illegal and unreported activities.

After the earthquake, the government decision of the Ramsar declaration was upheld, and the WCB focused mostly on short-term activities included in the plan. Other mid- and long-term conservation actions and goals were temporarily suspended, requiring further observation of the evolution of the wetland.

METHODS

We used mixed methods approaches (Creswell 2003) to collect data starting 18 months after the earthquake. First, we used qualitative research tools with exploratory and descriptive purposes. We organized eight consultation workshops, between June and August 2011, in three user group sectors (Fig. 2) that were defined based on the biogeographic setting (Stuardo et al 1993, Carrasco-Lagos 2003) and livelihood of local ES users: (a) the coastal border sector (Tubul) including mostly coastal fishers, who depend on diving and seaweed (pelillo) gathering, (b) the transition sector (Las Peñas, Santa Clara) represented mainly by rural dwellers whose mixed livelihoods include both marine resources and small-scale agriculture, (c) the inland sector (Raqui Chico, Bajo Raqui, Raqui Alto, Aguapié), which mostly included users dwelling in a 2-3 km fringe between the cultivated wetland plain and adjacent forested hills; this group mainly depends on farming and forestry resources for their livelihoods. A total of 61 local users participated, coordinated jointly with local leaders of neighborhood, fisher and indigenous associations.

The discussions where conducted based on guiding questions (Table 1) to learn about the wetland ES, their users, and the changes observed and impacts suffered by them following the earthquake. We used common language, instead of specialized terminology, to facilitate communication, for instance “the benefits obtained from nature” instead of ES; also, open questions were used to obtain users’ recall (Table 1), instead of using lists with choices to force their responses. ES categories were incorporated later in the analysis to group services according to the Millennium Ecosystem Assessment. We recorded the discussions and used flipsharts to synthesize and register the information. Qualitative data gathered provided a detailed and updated overview of the social-ecological system and the major changes observed after the abrupt uplift event. The qualitative appraisal allowed us to identify and prioritize the ES supporting community well-being and to characterize ES conditions before and after 27F, and was the basis for the design of quantitative instruments.

We used quantitative tools to complement the community-level qualitative assessment with a sample of individual perceptions. We applied a semistructured questionnaire to resource users in the same locations, using a purposive sampling design based on territorial coverage. A total of 154 individuals (54% men and 46% women) were surveyed in November-December 2011, including 77 users from the coastal border, 43 from the transition sector, and 34 from the inland sector. The questionnaire included:

- Closed questions to estimate how environmental changes have affected users’ well-being (Table 1). We first asked interviewees to retrospectively express their community and household levels of well-being in 2009, using a familiar 1 (lowest) to 7 (highest) scale used at Chilean schools. Then they were asked to score perceived current community and household levels of well-being using the same scale. Because perceptions of the community and household levels showed no statistical differences, we used the average score as the overall level of well-being.

- Open-ended questions to learn how people were coping with postearthquake conditions in terms of economic activities. We asked about economic activities performed five years before the earthquake and those currently performed (Table 1). Responses were compared, clustered into similar subsets, and codified for the analysis.

- Closed questions to prospectively inquire about users’ visions and interests regarding the future (Table 1). Respondents were first asked to express their preferences for the 18 most important services identified in the workshops, included in a close-ended list (Table 2). Then, they were asked about 17 development/conservation activities proposed by the researchers (Table 3) based on their informed knowledge about the area after formal and informal conversations during the exploratory stage. To collect users’ preferences for future ES and activities, they were asked for instance: “To maximize your well-being, how much agricultural land would you like to see in the wetland in year 2020?” A continuous line with two anchor points, “very much” and “nothing at all,” and a clear “indifference” line in the middle, was presented to interviewees to mark their responses. Answers were subsequently measured and scored as the positive or negative distances from the central zero point to facilitate the analysis.

We had a workshop with one indigenous organization and also a number of indigenous individuals attended other workshops and/ or responded to the survey in their capacity as members of nonindigenous neighbour associations. However, another five organizations were not interested in actively participating in the research. Hence, the study does not account for, nor is it

Table 1. Operationalization of shifting ecosystem services and human well-being as study variables.

Research phase/tool	Variable	Research question	Scale	Sample size
Qualitative / Workshop	Identification and prioritization of ecosystem services	What are the benefits you obtain from nature here around the wetland?	Open questions	8
		What is the level of importance of these services and resources for your well-being?	Very high – High – Intermediate – Low – Very low	
	Users' assessment of major changes in ecosystems services	What was the condition before 27F and what is it now?	Increased – Maintained – Decreased	
Quantitative / Semistructured questionnaire	Impacts on human well-being	What was the level of well-being of your community before 27F?; What was your household level of well-being before 27F? What is the level of well-being in your community after 27F?; What is your household level of well-being after 27F?	1 (lowest) to 7 (highest)	154
	Users' adaptations	Which economic activities did you normally develop in the 5 years before 2010? Which economic activities are you currently developing?	Open questions	
	Users' interests on different future pathways	To maximize your well-being, how many of the following 18 ecosystem services would you like to see in the wetland in year 2020? To maximize your well-being, how many of the following 17 activities would you like to see in the wetland in year 2020?	Nothing at all to Very much	

representative of, these formal indigenous groups' visions and interests over the ecosystem.

We performed the analyses using SPSS and Sigmastat software. We used t-tests to explore differences in human well-being perceptions before and after the earthquake. We used analysis of variance (ANOVA) with Tukey analysis or Kruskal-Wallis with Dunn's pairwise comparisons, depending on the nature of the data set, to contrast preference scores among different user groups.

RESULTS

Identification and prioritization of ecosystem services

Ecosystem users in TR identified a number of benefits obtained from the wetland, which we classified as 25 services sustaining human well-being. They corresponded to the 4 types defined in the Millennium Ecosystem Assessment related literature (Fig. 3). The greater concentration and variety of them were provisioning services. Figure 3 shows user groups' prioritization of the ES they use. In the three sectors, users valuate the diverse ES unevenly. Most differences were observed for provisioning services, which is consistent with distinct livelihood systems. Hence, coastal border users express high reliance on provisioning services associated with the estuary and the river mouth, while inland users rely more on agricultural services, firewood, and fodder. Transition sector users are reliant on both coastal and inland services. Biodiversity and other services, such as freshwater and aesthetic values, were considered highly relevant by users all around the wetland.

Users' assessment of major changes in ecosystems services

The 2010 coastal uplift and associated environmental changes produced varied effects on the availability of ES in the TR wetland. Figure 3 presents trends observed by local users in ES after the 27F abrupt disaster. The figure shows whether their availability increased, decreased, remained the same, or if both increase and decrease, occurred but in different areas. Results show that some services, such as seaweed and navigation throughout the wetland were totally lost after 27F. Other services such as landscape beauty and saline intrusion suffered overall decline, whereas timber and mooring places remained unaltered. By contrast, land availability and livestock fodder mostly increased in the wetland. Finally, freshwater services showed heterogeneous trends, with wells and springs that dried and other new sources that emerged.

Impacts on human well-being and users' adaptations

Average results showed an overall decrease in well-being perception in the area (Fig. 4). However, before-after differences were only statistically significant in the coastal border and transition sectors. Although human well-being was negatively affected by ecosystem changes in the coastal and transition sectors, inland users experienced milder impacts and expected improved conditions for their economic activities.

Fig. 3. Users' prioritization of wetland ecosystem services for human well-being and perceived changes in Tubul-Raqui after the 2010 earthquake. Legend: the size of circles represents the level of importance of each ecosystem service for human well-being as assessed by users (larger circles express higher importance); arrows represent the changes observed by users in ecosystem services after the earthquake, namely ↑ = increase; ↓ = decrease; → = maintenance; ↑↓ = increase and decrease in different places; NA = not assessed.

			Prioritization of ecosystem services			Changes perceived		
Type	Services	Use	Coastal border	Transition	Inland	Coastal border	Transition	Inland
Provisioning								
	Freshwater	Human (and cattle) consumption	●	●	●	↑	↑↓	↑↓
	Food	Meat, milk and cheese		•	●		↑	↑
		Agriculture		·	●		NA	↓
		Fish (sea and freshwater)	●	•	·	↑↓	↓	NA
		Mollusks (navajuela, navaja, huepo)	●	•		↑↓	↓	
		Ground shrimps	•	•	·	NA	NA	NA
		Non-timber forest products (murtilla, maqui, nalca)			•			→
	Fiber and fuels	Fodder ("llinto" / Spartina)		•	●		NA	↑
		Firewood	●	·	•		→	→
		Timber (exotic plantations)		·	·		→	→
	Biochemical products	Seaweed ("pelillo" / Gracilaria)	●	•	·	lost	lost	NA
	Transportation	Navigation and connectivity (rivers and canals)	●	•	·	↓	↓	↓
Regulation								
	Hidrological regimes	Water storage and moist retention for agriculture		•	·		→	↑
	Natural disasters	Shelter for vessels and mooring sites (estuary & riversides)	●			→		
	Pollution control and detoxification	Waste water and waste removal and cleaning		•			↓	
Cultural								
	Aesthetic	Landscape beauty and potential tourism	●	●	●	↓	↓	↓
	Spiritual and inspirational	Archaeological and cultural sites; identity		•	•		↓	↓
	Recreational	River beach		•			lost	
	Educational	Traditional knowledge (wetland accessing and use)			·			NA
Support								
	Biodiversity - fauna	Avifauna (swans, ducks, cranes)	●	●	●	↑↓	↓	↓
		Mammals (coypu, pudu, puma)	•	•	•	NA	↓	↑↓
	Nutrient cycle	Salt and fresh water interaction	●	●	·	↓	↓	↓

Table 2. Similarities and differences in user groups" mean preferences for future ecosystem services availability.

	Ecosystem services	Expressed as	Coastal border (SE)	Transition (SE)	Inland (SE)	H (P)
Similarities						
	Biodiversity	Abundance and variety of bird species in the wetland	9.27 (0.274)	9.06 (0.328)	9.66 (0.158)	0.962 (0.618)
	Freshwater	Freshwater in wetland watercourses and wells for human and cattle consumption	8.84 (0.369)	8.75 (0.388)	8.83 (0.327)	2.113 (0.348)
	Hydrological regimes	Freshwater storage and moist retention in wetland lagoons for agriculture	7.81 (0.450)	7.43 (0.627)	8.46 (0.360)	0.393 (0.821)
	Food / fiber and fuels	Land with native forests in the surrounding hills	8.03 (0.450)	7.07 (0.667)	8.09 (0.450)	2.251 (0.324)
	Transportation	Navigation and connectivity (in the rivers of the wetland)	7.66 (0.559)	7.70 (0.696)	6.22 (0.844)	3.881 (0.144)
	Aesthetic	Tourism development in and around the wetland	6.49 (0.608)	6.00 (0.904)	6.87 (0.611)	0.729 (0.694)
	Spiritual and inspirational	Protection of culturally significant sites in the wetland	5.21 (0.527)	4.12 (0.983)	5.13 (0.795)	0.333 (0.847)
	Fiber and fuels	Land with plantations in the wetland	-8.66 (0.464)	-6.21 (1.072)	-7.94 (0.703)	2.812 (0.245)
	Pollution control and detoxification	Waste water, waste removal, and cleaning	-9.16 (0.444)	-9.24 (0.476)	-9.92 (0.0794)	1.297 (0.523)
Differences						
	Food	Mollusks and fish in the river mouth	8.04† (0.448)	8.20† (0.558)	4.88‡ (0.698)	23.894 (< 0.001)
	Biochemical products	Seaweed in the wetland	8.19† (0.521)	7.25† (0.756)	3.74‡ (0.880)	36.769 (< 0.001)
	Biochemical products	Seaweed in the river mouth	7.29† (0.584)	7.55† (0.713)	3.74‡ (0.824)	29.221 (< 0.001)
	Natural disasters	Shelter for vessels and mooring sites (estuary and riversides)	7.12† (0.526)	7.10† (0.584)	2.79‡ (0.904)	21.698 (< 0.001)
	Nutrient cycle	Upstream saltwater intrusion and interaction with freshwater	6.93† (0.554)	6.39† (1.023)	0.55‡ (1.144)	24.932 (< 0.001)
	Food	Land suitable for agriculture in the wetland	-3.12† (0.819)	2.60‡ (1.026)	6.32‡ (0.903)	39.858 (< 0.001)
	Food	Land suitable for livestock in the wetland	-4.11† (0.756)	2.53‡ (1.091)	6.51§ (0.877)	52.608 (< 0.001)
	Fiber and fuels	Land with plantations in the surrounding hills	-5.45† (0.697)	-1.15‡ (1.076)	-2.81†,‡ (1.035)	12.328 (0.002)
	Pollution control and detoxification	Household treated gray water discharge in the rivers	-3.20† (1.088)	-8.38 (0.721)	-7.89† (1.001)	12.136 (0.002)

Superscript footnote symbols show significant differences among groups perceptions based on one-way analysis of variance (ANOVA) and Dunn's posteriori tests.

Size of user groups: Coastal border n = 77, Transition n = 43, and Inland = 34. Preferences were marked by respondents in a continuous line with anchor points "nothing at all" and "very much," and "indifference" in the middle; subsequently, responses were transformed to numbers between -10 ("nothing at all") and 10 ("very much") by measuring the distance from the "indifference" line (= 0).

To explore users' responses and adaptations to post earthquake conditions, we assessed changes in labor before and after 27F. Most respondents declared having developed at least two (up to six) different economic activities in the last five years. Frequent activities during the same period included seaweed harvesting (80 persons), artisanal fishing (44), agriculture (42), diving for benthic resources (37), and cattle raising (33). Other less frequent activities were forestry (8) and tourism (4) and also other activities not directly related to the wetland ecosystem (45).

Interviewees were asked about their post 27F main economic activities. Overall, 55.6% (n = 85) of surveyed users declared that their main economic activity changed and/or was affected after February 2010. The majority of them are users of the coastal (60%) and transition sector (38%), most of which (88%) declared seaweed exploitation among their three most important economic activities before 27F. Among those directly affected by ecosystem changes (n = 85), 31% has engaged in activities already developed before the earthquake. Most of them represent fishers and divers who, once seaweed resources were lost, were forced to intensify fish and shellfish resources exploitation. Complementarily, 19% correspond to women/wives traditionally involved in the seaweed exploitation that lost their source of income and are currently dedicated to the household. Twenty-two percent of surveyed users had to shift into new activities after the earthquake, converting

Table 3. Similarities and differences in user groups" mean preferences for future development/conservation alternatives.

	Development/conservation alternatives	Coastal border (SE)	Transition (SE)	Inland (SE)	H (P)
Similarities	Environmental research and education	9.06 (0.235)	8.70 (0.306)	8.07 (0.499)	5.375 (0.068)
	Efforts toward wetland recovery	9.28 (0.199)	8.53 (0.504)	7.57 (0.770)	4.108 (0.128)
	Small-scale community projects	7.84 (0.437)	7.62 (0.556)	8.19 (0.420)	0.232 (0.89)
	Self-employment promotion	8.59 (0.322)	6.87 (0.773)	7.84 (0.670)	1.849 (0.397)
	Tourism infrastructure	6.41 (0.486)	7.00 (0.845)	8.27 (0.578)	5.826 (0.054)
	Protected areas (restricted access)	4.14 (0.666)	3.53 (0.934)	2.20 (1.153)	1.538 (0.464)
	Other industrial developments	-5.98 (0.716)	-5.22 (1.096)	-3.82 (1.290)	3.616 (0.164)
	Concentration of land (large private properties)	-4.79 (0.631)	-5.60 (0.800)	-4.80 (1.094)	0.705 (0.703)
Differences	Public use areas (parks)	5.97† (0.456)	4.60†,‡ (1.021)	7.65‡ (0.720)	8.546 (0.014)
	Wage labor promotion	0.11† (0.899)	9.14‡ (0.311)	8.56‡ (0.498)	62.513 (< 0.001)
	Irrigation technologies for agriculture	2.69† (0.634)	4.23† (1.056)	8.75‡ (0.303)	32.594 (< 0.001)
	Hydraulic infrastructure to restore the wetland	2.62† (0.843)	5.57‡ (1.071)	5.92†,‡ (0.857)	8.793 (0.012)
	Aquaculture projects in the wetland	1.48† (0.875)	6.31‡ (0.980)	5.18†,‡ (0.960)	18.086 (< 0.001)
	Wind farms in and around the wetland	-1.76† (0.727)	0.08†,‡ (0.959)	3.31‡ (1.153)	14.246 (< 0.001)
	Large-scale private projects	-2.61† (0.907)	1.60‡ (1.168)	-0.56†,‡ (1.480)	7.169 (0.028)
	Division of land (small private properties)	-1.64† (0.672)	-2.47† (1.170)	2.28‡ (1.348)	9.993 (0.007)
	Authorizations for burning pastures (to increase fodder)	-8.22† (0.416)	-5.23 (1.109)	-3.51† (1.426)	6.236 (0.044)

Superscript footnote symbols show significant differences among groups perceptions based on one-way analysis of variance (ANOVA) and Dunn's posteriori tests.

Size of user groups: Coastal border n = 77, Transition n = 43, and Inland = 34. Preferences were marked by respondents in a continuous line with anchor points "nothing at all" and "very much," and "indifference" in the middle; subsequently, responses were transformed to numbers between -10 ("nothing at all") and 10 ("very much") by measuring the distance from the "indifference" line (= 0).

mostly into the commercial or services sector or entering the labor market, e.g., regional forestry/pulp industry or salmon industry in southern regions. Around 7% of interviewees took the opportunity to diversify their livelihoods, expanding their activities mainly into small-scale businesses, e.g., food, grocery stores. Finally, 18% of surveyed users were unemployed after 27F and 4% were retired.

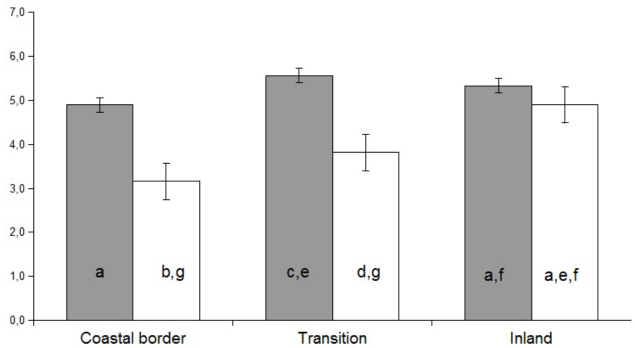
Users' interests on different future social-ecological pathways

Results show common preferences and visions among wetland users, associated with ES and activities considered important for sustaining future human well-being in TR, irrespective of the place of residence of respondents. Diversity of bird species and availability and storage of freshwater in the wetland are the upmost important ES in all three user groups (similarities in Table 2). Users expressed the highest preferences for environmental research and education, wetland restoration efforts, and small-scale community projects as core pillars for the area in 2020 (similarities in Table 3). Results also highlight similarities between user groups regarding ES and human activities which are considered as detrimental to other services and to human well-being. These include exotic species plantations and waste disposal in the wetland (Table 2), and the implementation of industrial developments and further concentration of land property in the area (Table 3).

Our study also found significant differences among ecosystem user visions about possible futures in the TR wetland. Tables 2 and 3 show ranked preferences for ES and development/conservation activities where significant differences among group averages exist. In this case, results describe particular future interests of each user group that are considered to enhance people's well-being. Coastal border and transition sector users are more interested in fish and benthic resources than inland users;

whereas the latter are much more concerned about agriculture and livestock than the others (differences in Table 2), with respect to possible future development/conservations activities (differences in Table 3). For instance, all sectors were positive about the establishment of public use areas in the wetland, but inland users presented the highest score. Transition and inland users showed higher preference scores for wage labor promotion policies than coastal border interviewees. Inland users exclusively expressed very high preferences for irrigation technology to improve agriculture. Finally, the frequent practice of burning pastures in the wetland to obtain increased and tendered fodder for cattle was refused on average by all sectors; however, relatively higher scores and the high variance in the inland suggest this practice represents conflicting positions among farmers.

Fig. 4. Average user groups' perceptions of community and own household well-being conditions before (retrospectively measured; grey bars) and after (white bars) the 2010 earthquake; well-being is scored using the Chilean school grading scale; 1 is the lowest mark and 7 the highest; error bars represent standard deviation; significant differences are represented by different letters and analyzed with one-way analysis of variance (ANOVA) and Dunn's posteriori tests.



DISCUSSION

Using the ES framework allowed us to describe local communities' reliance on wetland ES for sustaining their livelihoods and providing well-being. The analysis shows distinct, overlapping, and diversified livelihood systems around the wetland, for which different sets of ES have been traditionally relevant. Raudsepp-Hearne and coauthors (2010) suggested the existence of several subsystems within a provincial landscape associated to particular ES bundles. Similarly, our findings suggest the presence of three intertwined social-ecological subsystems within the study area. In TR, the largest differences can be observed between coastal and inland users, which depend mostly on marine/coastal and farmland/forest services and resources, respectively. Transition users develop a mixture of coastal and inland activities. The presence of these subsystems allowed us to detect heterogeneity in impacts, with potential winners and losers.

Valdovinos and coauthors (2010) and MMA-Centro de Ecología Aplicada (2010) described the environmental impacts from the 27F, and highlighted important socioeconomic impacts from the drying of a large wetland area that was the habitat for the valuable pelillo seaweed. Our study confirms and complements these findings by looking at a broader set of ES. Results show that the 27F earthquake triggered heterogeneous changes in multiple ES in TR, including total loss, reduction, maintenance, and increase in their availability. Daw and coauthors (2011) have suggested the need to make spatial and demographic distinctions to understand community well-being in relation to ES. In TR, observed impacts were unevenly distributed along the wetland and therefore affected local users in distinct ways. With respect to the impact on communities of ES loss and reduction, levels of well-being considerably declined after 27F in the coastal and transition sectors, which depended on the provisioning service of seaweed for harvest. By contrast, in the inland communities that did not lose any critical resource, the levels of well-being are indistinguishable from the pre-earthquake condition. Even though all sectors experienced ES decline, the most significant detrimental effects of the abrupt transformation are associated with the total loss of the key wetland resource pelillo. This finding reinforces the fact that the seaweed was a critical contributor to the local economy, and underlines the emergence of a group of harmed users, namely seaweed harvesters and cultivators who are the losers from the abrupt transformation.

The assessment of changes in multiple ES allowed for the detection of a group of potential beneficiaries from the transformations. As a consequence of the uplift, farmland areas increased and improved because they are no longer exposed to saltwater intrusions, generating opportunities for inland sector users to increase productivity. They become the winners from the abrupt transformation, with potential economic benefits. These results suggest that even in a relatively small area, abrupt environmental transformations can produce spatially diversified and multidirectional impacts on ES and different user groups. Overlooking local distinctions can lead to misleading assessments of the distribution of the costs and benefits after abrupt regime transformations.

People can respond and adapt to environmental changes in multiple ways depending on the kind of perturbations and the level of organization of the social system (Smit and Wandel 2006, Kates et al. 2012). Our results show four response typologies after the 27F: intensification, reduction, reconversion, and diversification of economic activities. These multiple adaptations heavily rely on pre-existing diversified livelihood systems, allowing for adjustments in a multiple-activity matrix rather than forcing radical shifts. More than half of interviewees in TR changed their main economic activity, mainly through intensification of other activities. Results suggest that the responses observed in TR represent autonomous and reactive adaptations, which are activated at the individual and household levels in the event of an abrupt regime shift. These underlying capacities can be considered latent, and may be useful to respond to any other perturbation with negative effects for communities (Vincent 2007, Jones et al. 2010), such as fall in market prices or resource depletion. In TR, it is important to highlight that livelihood portfolios of people prior to the abrupt shift determined response options (Adger 1999, Adger et al. 2002, Marschke and Berkes 2006). Thus results show a lack of capacity to create untried new beginnings in the TR wetland from which user groups could evolve to fundamentally new ways of living after the transformation (Walker et al. 2004).

Our results highlight the existence of trade-offs between ES in TR and associated costs and benefits from the abrupt shift, and suggest the need to monitor likely unintended consequences of alternative ES exploitation. Within a vulnerable ecosystem, improved opportunities in some sectors may represent threats for other areas. In an unpublished study by Centro de Ecología Aplicaca it is reported that existing drainage programs may threaten wetland sustainability in the midterm in TR. Valdovinos and coauthors (2010) underline hunting and deforestation as the main historical anthropogenic threats to the TR wetland. The introduction of dogs and the use of fire to obtain more tender shrubs for cattle have also been discussed within the WCB as factors that may risk biodiversity conservation in the wetland after the uplift. Our study sheds lights on other warnings: (1) the increased economic reliance on shellfish resources may threaten the sustainability of benthic stocks in the Gulf; (2) the improved conditions for livestock in the inland sector of the wetland represent new pressures that may reduce wetland resilience and affect the slow recovery process; (3) the higher dependence, especially during the dry season, on the provision of freshwater that flows from nearby forested hills to sustain key wetland services, such as avifauna, flora, and aesthetic enjoyment of the landscape.

Our findings identified existing dissimilarities and commonalities in users' visions and interests associated with wetland ecosystem services for the future. Main shared visions about future social-ecological pathways are linked to the importance of benefits provided by bird species, freshwater, and native forest. These results may appear as contradictory in the face of massive loss of seaweed, a provisioning service with economic importance. However, the presence and abundance and diverse birds and the availability of copious water in the wetland refer to key elements of the ecosystem and the identity of local people. Nash (1993) has discussed the close connection between language, landscape, and identity, which is commonly captured in place names. In our case, Tubul means turbid in the indigenous language, meaning the particular color of wetland and estuary waters; whereas Raqui means "bandurria" (Black-faced Ibis, *Theristicus melanopis*), a characteristic Chilean bird that inhabits marshes and lake shores. The importance of birds and water for local users all around the wetland is more likely to be associated with symbolic and cultural values than with their utilitarian exploitation. In this way birds and water represent both supporting and cultural ES. In addition to the importance of native forests in the surrounding hills, considered by users as better water sources and reservoirs than plantations, these three ES are indicators of a healthy ecosystem with the capacity to sustain biodiversity and human well-being in the long term. With respect to the most common highly preferred activities to be promoted in the future, environmental research and education in the wetland represent nonextractive and noninvasive alternatives that may provide direct and indirect economic benefits to local users when combined with tourism. The high interest for wetland restoration is associated with the hope and expectation of restoring the ecosystem to a pre 27F state, which is also associated with pelillo aquaculture and navigating the wetland. Focusing on these services and activities has the potential to strengthen collaboration among users and enhancing existing management platforms, for instance the WCB, with respect to decisions about wetland sustainability and conservation initiatives.

Complementarily, common rejection of certain uses, such as exotic species plantation and waste disposal in the wetland, highlight shared perceptions of risk and threats that need to be analyzed. The assessment of local users' future visions and interests provide useful insights to decision makers on how to prioritize and balance sustainability, management, and conservation alternatives. Shared social-ecological pathways provide opportunities for consensus and trust building (Chapin et al. 2009, Gelcich et al. 2009).

We draw partially on informants' reports of disaster-related experiences, which are by nature subjective. These accounts may be affected by the shocking experience and the impacts suffered and may therefore be not entirely reliable. However, literature suggests that a good recall of disaster experiences is actually possible, even over long periods of time (Baum et al. 1983, Verger et al. 2003). In our study, the consistence of results with other biophysical reports and the congruence between the magnitude of transformations and the impacts on levels of well-being in different geographical sectors, suggests the validity of respondents' recall. Natural disasters are unexpected and it is unlikely to plan for diachronic designs to count on systematic pre-event information (Bravo et al. 1990). Therefore, retrospectively assessing people's experiences represents a practicable method in the face of natural disasters and abrupt ecosystem transformations.

CONCLUSION

We are aware of no study that has applied the ES framework to investigate sudden and abrupt natural catastrophes and associated social-ecological changes. In this research, the use of the ES framework has proven to be useful for the study of abrupt regime shifts in a coastal wetland. Focusing on the entire range of ES rather than doing single-service analyses has allowed us to capture trade-offs among ES (Carpenter et al. 2006). In TR, a preliminary identification and prioritization of ES by local users highlighted not only the negative side of abrupt changes, namely the loss of pelillo, but also opportunities, such as those associated with livestock. Further, as suggested by Granek and coauthors (2010), the Millennium Ecosystem Assessment framework proposes a common language and a comprehensive narrative to investigate and communicate current and future social-ecological changes with the involvement of stakeholders. In this context, the use of ES as a component of the agenda of global environmental change research has the important potential to link the consequences of abrupt transformations and regime shifts with the consequences for human well-being and future trajectories or pathways for the coupled social-ecological system.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/5633

Acknowledgments:

The authors thank all participants of the study, for their time and for the knowledge they shared. Thanks to the leaders of the eight local organizations involved, for their invaluable contribution in coordinating workshops and surveying, to Patricia Carrasco from *the Secretaría Regional Ministerial del Medio Ambiente. To the "Mesa de Trabajo para la Conservación del Humedal Tubul-Raqui" for their interest, information, and comments. We thank Carolina Vargas and Andrés Camaño, Gerencia Corporativa de Medio Ambiente, Seguridad y Salud Ocupacional of ARAUCO, for supporting this research and providing ideas and suggestions. We also thank one anonymous reviewer who provided valuable and constructive critiques that helped to improve the article. We acknowledge the support of FONDECYT grant 1120103 and the Iniciativa Cientifica Milenio Centro de Conservacion Marina of the Ministerio de Economía, Fomento y Turismo. The P. Universidad Católica de Chile, Department of Ecology, provided facilities in Santiago to carry on and complete this research.*

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