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Hydrological Sciences Journal
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/thsj20

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Version of record first published: 16 Dec 2011.

To cite this article: Sandra P. Vilardy , José A. González , Berta Martín-López & Carlos Montes (2011): Relationships between hydrological regime and ecosystem services supply in a Caribbean coastal wetland: a social-ecological approach, Hydrological Sciences Journal, 56:8, 1423-1435

To link to this article: http://dx.doi.org/10.1080/02626667.2011.631497

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Relationships between hydrological regime and ecosystem services supply in a Caribbean coastal wetland: a social-ecological approach

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Received 29 July 2010; accepted 8 August 2011; open for discussion until 1 June 2012

Editor Z.W. Kundzewicz; **Guest editor** M.C. Acreman

Citation Vilardy, S.P., González, J.A., Martín-Lopez, B. and Montes, C., 2011. Relationships between hydrological regime and ecosystem services supply in a Caribbean coastal wetland: a social-ecological approach. *Hydrological Sciences Journal*, 56 (8), 1423–1435.

Abstract The Ciénaga Grande of Santa Marta is Colombia's largest coastal wetland and one of the most important in the Caribbean. In this paper we evaluate the complex linkages existing among the social-ecological history, provision of ecosystem services and human well-being as perceived by local stakeholders. The most critical anthropogenic impacts occurred during the last 50 years in the period following the construction of the Ciénaga-Barranquilla highway. The changes to the social-ecological system have severely altered hydrological dynamics, reduced mangrove forest coverage and affected the composition of fisheries, with direct and indirect effects on the ecosystem services provision and on the well-being of the local people. Despite the ambitious restoration programmes put in practice during the last two decades, the social-ecological impacts of large infrastructure developments are visible today. The paper offers insights that can improve environmental decision making and promote adaptive governance in coastal wetlands.

Key words artisanal fisheries; ecosystem services; human well-being; hydrological regime; mangroves; social-ecological history

Relations entre régime hydrologique et fourniture de services écosystémiques dans une zone humide côtière des Caraïbes: une approche socio-écologique

Résumé La grande Ciénaga de Santa Marta en Colombie est la plus grande zone humide côtière et l'une des plus importantes dans les Caraïbes. Dans cet article nous évaluons les liens complexes existant entre l'histoire socio-écologique, la fourniture de services écosystémiques et le bien-être humain tels que perçus par les acteurs locaux. Les impacts anthropiques les plus critiques sont survenus au cours des 50 dernières années, au cours de la période suivant la construction de l'autoroute Ciénaga-Barranquilla. Les changements du système socio-écologique ont sérieusement altéré la dynamique hydrologique, réduit la couverture forestière de la mangrove et affecté la composition des stocks de poissons, avec des effets directs et indirects sur la fourniture des services écosystémiques et sur le bien-être de la population locale. Malgré les programmes de restauration ambitieux mis en pratique au cours des deux dernières décennies, les impacts socio-écologiques du développement des grandes infrastructures sont visibles aujourd'hui. L'article propose des idées qui peuvent améliorer la prise de décision en matière d'environnement et promouvoir une gouvernance adaptative dans les zones humides côtières.

Mots clefs pisciculture artisanale; services écosystémiques; bien-être humain; régime hydrologique; mangroves; histoire socio-écologique

INTRODUCTION

The world is facing a natural resource crisis (Acheson 2006) precipitated by natural, climatic and anthropogenic stressors. These stressors are predicted to increase in frequency and intensity (Hughes *et al.* 2007). A consequence of these pressures is a loss of ecosystem services, the benefits that humans derive from natural ecosystems (Hassan *et al.* 2005, MEA 2005). Ecosystem services may be characterized as the aspects of ecosystems that are utilized (actively or passively) to maintain human well-being (Fisher

ISSN 0262-6667 print/ISSN 2150-3435 online
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http://dx.doi.org/10.1080/02626667.2011.631497
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et al. 2009) and may be classified as provisioning, regulating and cultural services (MEA 2005, Hein *et al.* 2006).

Losses of ecosystem services are often mediated by the human motivation to manage only the few services that are the most profitable. The use of management policies of this type usually results in a loss of other social, cultural, or ecological benefits (Hicks *et al.* 2009).

Changes in an ecosystem's state could promote changes in the flow of ecosystem services supplied and thereby affect human well-being at different spatial scales (MEA 2005, Martín-López *et al.* 2009). In particular, the degradation of ecosystems poses a direct threat to rural local communities because these communities depend heavily on those ecosystem services provided at a local scale (Díaz *et al.* 2006, Dasgupta 2010). For this reason, consultation with the local community is becoming a prerequisite for understanding how people use, perceive, and value ecosystem services (Pickaver *et al.* 2004).

Coastal ecosystems are important providers of ecosystem services essential for human well-being, such as storm buffering, fish production, and enhanced water quality. They are particularly sensitive to environmental degradation processes and to the effects of current global change (Agardy *et al.* 2005, UNEP 2006). Some coastal ecosystems have experienced an alarmingly fast rate of change because of unplanned human pressure on the resources they provide. For instance, at least 35% of the area of mangrove forests has been lost in the past two decades (Valiela *et al*. 2001, Alongi 2002). These changes have affected the delivery of ecosystem services (Koch *et al*. 2009).

In this context, social-ecological systems theory provides a useful perspective for analysing the use of ecosystem services (Andersson *et al.* 2007). However, such theory has frequently lacked integration with social-ecological history. To understand the natural dynamics underlying the provision of ecosystem services and the ways that people use and manage these services, it is essential to explore the history of the relationships between ecosystems and social systems. In fact, the interconnectedness of history and ecology has received increasing attention (for example see Meine 1999, Bowman 2001, Crumley 2007), because it: (a) aids understanding of key factors and processes that generated current environmental problems; (b) fosters better informed management and policy decision making; and (c) places natural sciences in a wider interdisciplinary context (Szabó 2010).

The main objective of this paper is to analyse how the historical changes in hydrological dynamics have affected ecosystem services provision and human well-being in the Ciénaga Grande of Santa Marta (CGSM), the largest and most important coastal wetlands system in Colombia. In doing so, we specifically: (a) review the environmental history of the CGSM to identify different alternative states of the social-ecological system; (b) explore historical changes in several key factors that determine the integrity of the CGSM; (c) identify the most critical ecosystem services for maintaining human well-being provided by the CGSM; and (d) analyse how the changes in key factors that determine social-ecological dynamics have affected the use of ecosystem services by different stakeholders. Finally, we develop some insights into the importance of social-ecological history and the ecosystem services framework for coastal wetlands management, and we discuss possible strategies to promote adaptive governance and improve environmental decision making.

STUDY AREA: THE CIÉNAGA GRANDE OF SANTA MARTA

The CGSM eco-region is located on the Caribbean coast of Colombia and is part of the peri-Caribbean arid belt, a bio-geographical region characterized by a constant hydrological shortage resulting mainly from the drying effects and the influence of the trade winds of the Northern Hemisphere. The region's inter-annual climate dynamics are also strongly affected by the El Niño Southern Oscillation (Blanco *et al.* 2006).

Comprising approximately 4900 km^2, the eco-region consists of a complex mosaic of ecological units within a matrix of coastal and marine wetlands. These ecological units include the largest (554 km^2) and most diverse mangrove forest in Caribbean Colombia, dry forests, different types of xerophytic vegetation, pasturelands, traditional subsistence crops, and industrial plantations of bananas and oil palms (Polania *et al.* 2001; MAVDT and CORPAMAG 2002, Vilardy *et al.* 2011). The eco-region includes 1300 km^2 of wetlands and water bodies. These aquatic habitats include 730 km^2 of swamps, lagoons, channels, alluvial plains and streams, and 570 km^2 of marine waters (Bernal and Betancur 1996) (Fig. 1). The coastal lagoons and mangrove forests have supported the development of highly diverse communities of molluscs, crustaceans, fish, birds, reptiles and mammals. Additionally, the eco-region is the most important area along the

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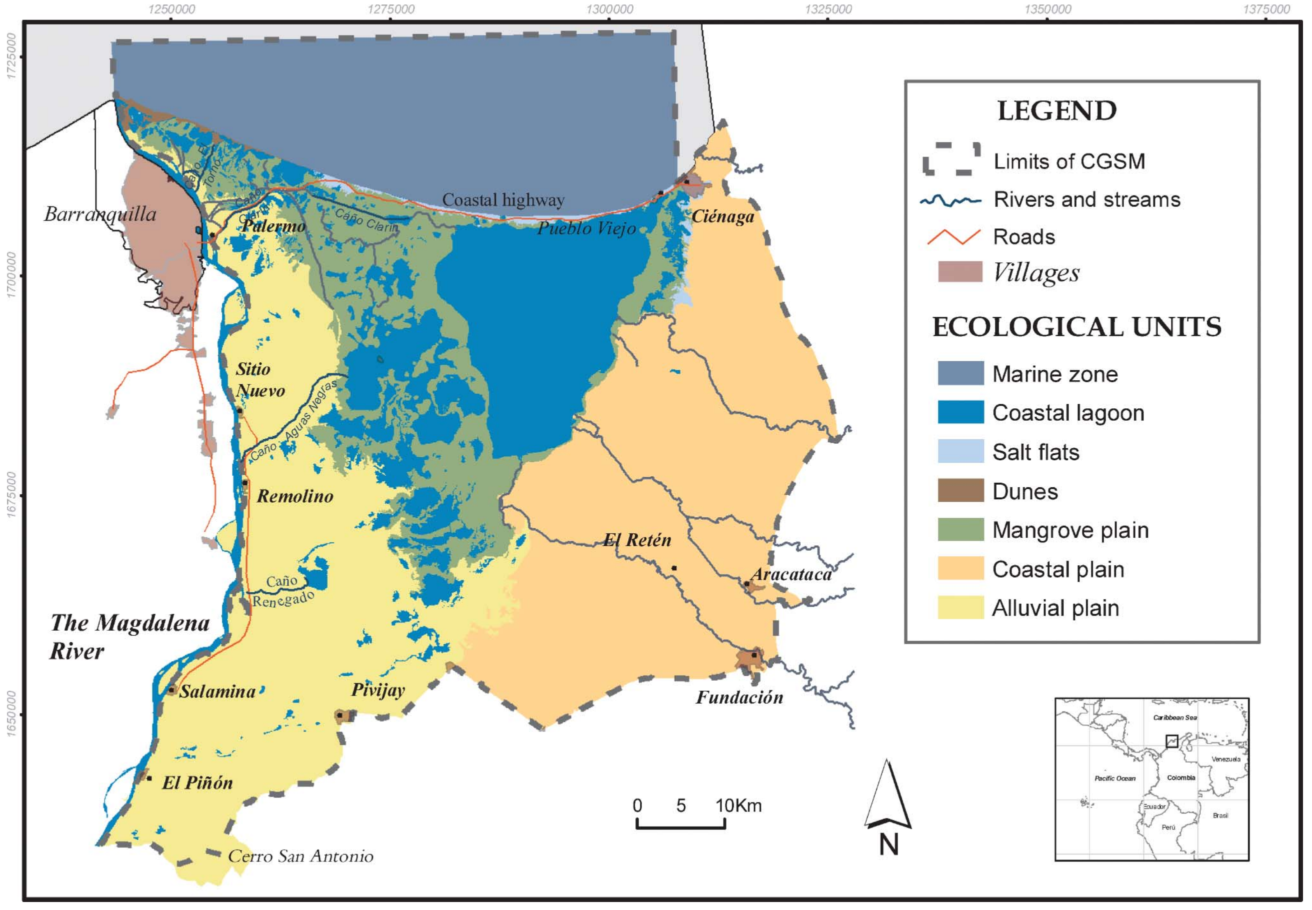

Fig. 1 Map of the study area, showing the different ecological units present in the eco-region.

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Caribbean coast of Colombia for resident and migratory waterbirds (Botero and Rusch 1994). Some critically endangered species, such as the manatee (*Trichechus manatus*) and the American crocodile (*Crocodylus acutus*), have also been recorded here (PROCIÉNAGA 1995). The ecological value of the CGSM was recognized through the protection of two areas in the eco-region: the Isla Salamanca Natural Park, established in 1964, and the CGSM Fauna and Flora Sanctuary, established in 1977. In addition, the CGSM was granted international recognition as a RAMSAR site in 1998 and as a Biosphere Reserve in 2000.

The study area includes 11 municipalities. Its total human population in 2005 was 341 428, of whom 55.4% had unsatisfied basic needs (an indicator that measures household access to a series of basic services, such as sanitation, housing conditions, and educational level), high rates of illiteracy (27.3% of the total population), and restrictions on access to drinkable water (68.5% of the total population) (Vilardy *et al.* 2011).

During the 20th century, the area became very important to the local and national economy as a source of fish and seafood and for commercial cultivation and associated agroindustrial development (MAVDT and CORPAMAG 2002). Over the past few decades, national and regional policies have promoted the development of a productive infrastructure to support large banana and oil-palm plantations and coal-mining ports (Vilardy *et al.* 2011).

METHODS

To study the social-ecological history of the CGSM, we first conducted a systematic literature review (Vilardy and Cuadrado 2011). A set of 810 publications spanning the period 1935–2009 was analysed. The review included published references (43.9% of total publications) and grey literature (56.1% of total publications). Based on this review, we identified and characterized the historical changes occurring during the last 60 years in the key factors affecting social-ecological dynamics in the CGSM eco-region.

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We identified these key factors as the hydrological regime, the degree of coverage by mangrove forest and fisheries dynamics.

We also conducted a two-day workshop in January 2008 to test the main results of the previous systematic review, to identify the ecosystem services provided by the CGSM eco-region and to explore the relationships between these ecosystem services and the key factors identified. Based on de Groot *et al.* (2006), we derived a classification of ecosystem services. We designed this classification to reflect the social-ecological complexity of the CGSM eco-region. The workshop brought together 60 participants from academia, government, and non-governmental organizations. These participants represented a broad range of disciplines and had extensive experience in the study area. For more details about this workshop, see http://www.repensandolacienaga.com.

Finally, we carried-out 131 semi-structured interviews in six municipalities in the study area and in the cities of Santa Marta and Bogotá to identify the stakeholders' perceptions of the use of the ecosystem services provided by the CGSM and of the trends associated with these services. The population sampled was initially selected at random. We then applied the snowball sampling technique. We asked our key informants to name other people who should be contacted by the researchers. The interviewees came from diverse backgrounds. They included local users (mostly from the agricultural and fishing sectors), community leaders, and resource managers. The interview compiled information regarding three major topics: (1) the nature and source of the ecosystem services provided by the CGSM; (2) the changes in the way each of these services has been offered during the interviewee's use; and (3) the importance of each of these services for the interviewee's well-being. We used contingency tables (with χ^2 tests of statistical significance) to analyse the associations between the historical trends in each of the ecosystem services identified and the importance of these services for the well-being of the respondents.

RESULTS

The social-ecological history of the CGSM

We identified seven major periods in the history of the CGSM. Each period was characterized by different predominant land use types and different management policies, influenced by social, cultural and environmental determinants. Figure 2 shows all of these historical periods. In this paper we will present a detailed treatment of the three most recent periods, a time span of ca. 50 years, during which the rates of change have accelerated and the intensity of the transformations occurring has been more severe. These processes have determined the current social-ecological dynamics of the CGSM.

We identified an "environmental crisis period" (*ca* 1956–1980) marked by various major interventions that produced critical changes in the hydrological flows and thereby severely affected the functioning of the system (Botero and Mancera-Pineda 1996). The most important of these interventions was the construction of the Ciénaga-Barranquilla highway, which began in 1956. The highway blocked important communication channels between the sea and the Ciénaga Grande lagoon. Mangrove forest degradation followed in the western part of the system, as did massive occurrences of oyster mortality. Changes in the composition of the mangroves and a reduction in the fish harvest also occurred (PROCIÉNAGA 1995). Other interventions that affected the system during this period included: (a) the building of a new road parallel to the right margin of the Magdalena River—which is the largest river in Colombia with 1538 km in length (Kauffman and Hevert 1973), an average annual water discharge of 7232 m^3 s^{-1} and an annual sediment load of 144×10^6 t year^{-1} (Restrepo and Kjerfve, 2000, Restrepo *et al*. 2006)—and the construction of dams and other infrastructure to prevent flooding, reducing the amount of freshwater flowing into the system; (b) the construction of new dams and channels to promote commercial mangrove wood extraction; and (c) the expansion of monocultures in the eastern part of the system. This expansion was accompanied by an increase in the amounts of water extracted from the rivers descending from the Sierra Nevada mountain range, reducing freshwater flows and increasing the loading of agrochemicals into the lagoon complex.

The subsequent "environmental management period" (*ca* 1981–1998) was marked by a coordinated institutional response to the social-ecological crisis facing the CGSM. This period began with the presentation of the first environmental management plan for the area in 1981. The plan included a wide range of actions for ecological restoration and for strengthening social and economic conditions, particularly those of fishermen (Simons 1981). Beginning in 1992, the megaproject PROCIÉNAGA generated a remarkable change in the CGSM. The project restored

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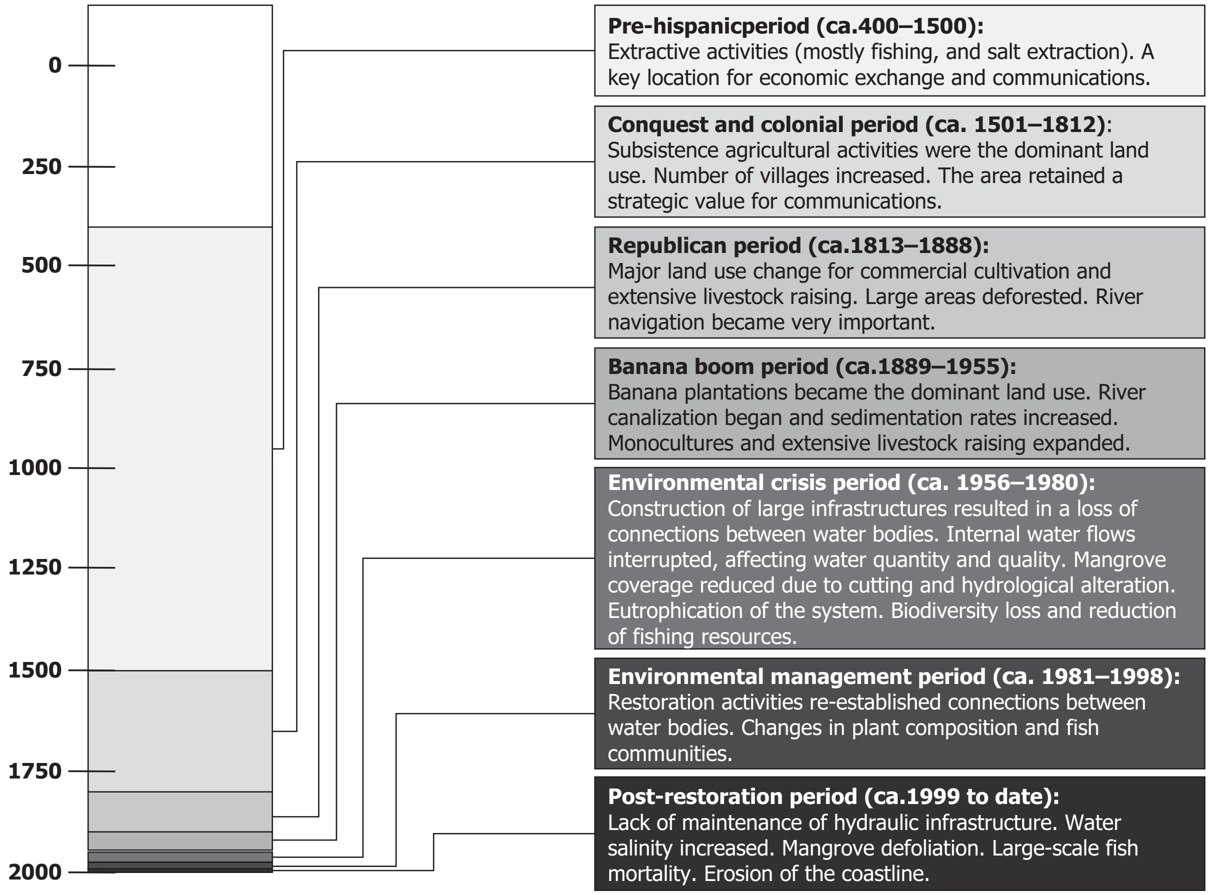

Fig. 2 Social-ecological history of the Ciénaga Grande of Santa Marta, showing the major historical periods and the main anthropogenic interventions that caused changes in the system dynamics.

hydrological flows by re-establishing connections of lagoons with the sea and the Magdalena River and it created new opportunities for inter-institutional dialogue and formal cooperation. Nevertheless, the social and economic crisis persisted and was further aggravated by the presence of armed guerrilla groups in the area.

The final "post-restoration period" (*ca* 1999 to date) was essentially a transition phase. Initially, the extreme La Niña event of 1999–2000 produced large inputs of freshwater to the system and a drastic change in fish composition (Blanco *et al.* 2006). Moreover, after the termination of the PROCIÉNAGA project in 2001, the lack of maintenance of the hydraulic infrastructure resulted in a sharp increase of salinity, renewed mangrove mortality, and a reduction of fishing resources. The persistent social crisis was marked by increased violence, the appearance of paramilitary groups in the area, and the massacres of fishermen and peasants. A lack of institutional response also characterized this transitional period, which continues today.

Historical trends in the key factors affecting social-ecological dynamics

In this section, we describe in detail the effects on the region of major historical changes in three key factors: the hydrological regime of the CGSM, the coverage of mangrove forests, and the composition of local fisheries.

Hydrological regime The hydrological regime was first impacted by anthropogenic alterations during the "banana boom" period (*ca* 1889). During this period, national development policies promoted the expansion of banana plantations in the eastern part of the CGSM, and water districts were created to regulate irrigation (Meisel 2004). Water for irrigation was taken from the rivers descending from the foothills of the Sierra Nevada mountain range. The use of these rivers for irrigation generated a 60% decrease in the amount of freshwater entering into the system (Espinosa *et al*. 1995). During the 1930s, the promotion of cultivation and cattle ranching at the

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national level produced dramatic deforestation rates in mountain areas and an increase in sedimentation rates. The effects of these changes on the lower parts of the Magdalena River basin were the sedimentation of streams and a reduction in the volume of water entering the CGSM lagoon complex (Botero and Mancera-Pineda 1996, Restrepo *et al*. 2006). These events marked the beginning of a series of direct and indirect impacts on the hydrological regime (Rivera-Monroy *et al*. 2006).

The major anthropogenic alteration in hydrological dynamics began in 1956, when the environmental crisis period started. The construction of a highway parallel to the coastline interrupted all but one of the natural connections between the sea and the lagoon complex (Espinosa *et al*. 1995, Botero and Mancera-Pineda 1996, Cardona and Botero 1998). The hydrological regime was also affected by a decrease in the amount of freshwater entering the system due to stream sedimentation, the obstruction of water flows, and an increase in contaminants (see Appendix A for more details). Finally, the construction of channels during the period 1960–1976 to allow the extraction of mangrove wood modified the hydrological flow pattern in the mangrove forests (Hernández *et al.* 1980).

The severe environmental degradation that followed these changes motivated the national government and several international organizations to develop plans to restore the original dynamics of the system (Botero and Salzwedel 1999). The initial restoration project included the reopening of four connections with the sea and then the PROCIENAGA project included the rehabilitation of six streams (Caño Clarin Nuevo, Caño El Torno, Caño Almendros, Caño Alimentador, Caño Renegado and Caño Aguas Negras) and other three connections with the sea (Fig. 1). These measures allowed more freshwater from the Magdalena River to enter the lagoon complex. An additional flow of 150 m^3 s^{-1} was achieved by these measures. However, this change added large quantities of sediment (910 000 t per day) to the system (Table 1), had immediate impacts on salinity (Table 1) (Elster 2000, Rivera-Monroy *et al*. 2006), and promoted the introduction of cattail (*Typha dominguesis*) (Reyes *et al.* 2004), which has an impact on the mangrove forest because it severely limits the dispersion of propagules (Villamil Echeverri 2003). These alterations soon blocked the rehabilitated streams and rendered the restoration inoperative by 2000, in the post-restoration period (Table 1) (Blanco *et al.* 2006, Rivera-Monroy *et al.* 2006). This situation and the lack of maintenance of the hydraulic infrastructure returned the hydrological regime to its previous state, as reflected in the salinity values of the Pajarales and the Ciénaga Grande lagoon complex (Table 1) (INVEMAR 2001, 2003, 2004, 2005).

Mangrove coverage Besides the water bodies, the most representative element in the eco-region is the mangrove forest. The loss of approximately

Table 1 Changes in the sediment discharge of the Magdalena River, the depth of the CGSM lagoon, and the water salinity during recent historical periods. (SD: standard deviation, given in parentheses).

Period	Period	Sediment load[a] (10^3 t d^{-1}) (SD)	Depth of CGSM (m)	Salinity (SD)		
				Coastal lagoon	Mangrove	Interstitial water
Environmental crisis	1972–1980	334.22 (67.80)	2.3[b]	20[b]		
Environmental management	1981–1992	435.42 (147.19)	1.7[c]	17.33 (5.30)[d]	41.67 (5.69)[d]	75.00[e]
	1993–1995	440.00 (80.47)				
	1996–1998	443.33 (231.16)		14.67 (4.32)[d]	11.00 (13.23)[d]	
Post-restoration	1999–2001			9.67 (8.14)[d]	8.00 (8.72)[d]	44.00 (3.61)[d]
	2000–2004		1.5[e]	18.25 (0.96)[d]	23.25 (5.74)[d]	61.00 (12.41)[d]

[a]Sediment load of the Magdalena River at the downstream Calamar station (data source: Restrepo and Kjerfve 2000, Restrepo *et al*. 2005).
[b]Data source: Wiedemann (1973).
[c]Data source: Bernal and Betancur (1996).
[d]Data source: Invemar (2004).
[e]Data source: Rivera-Monroy *et al*. (2006).

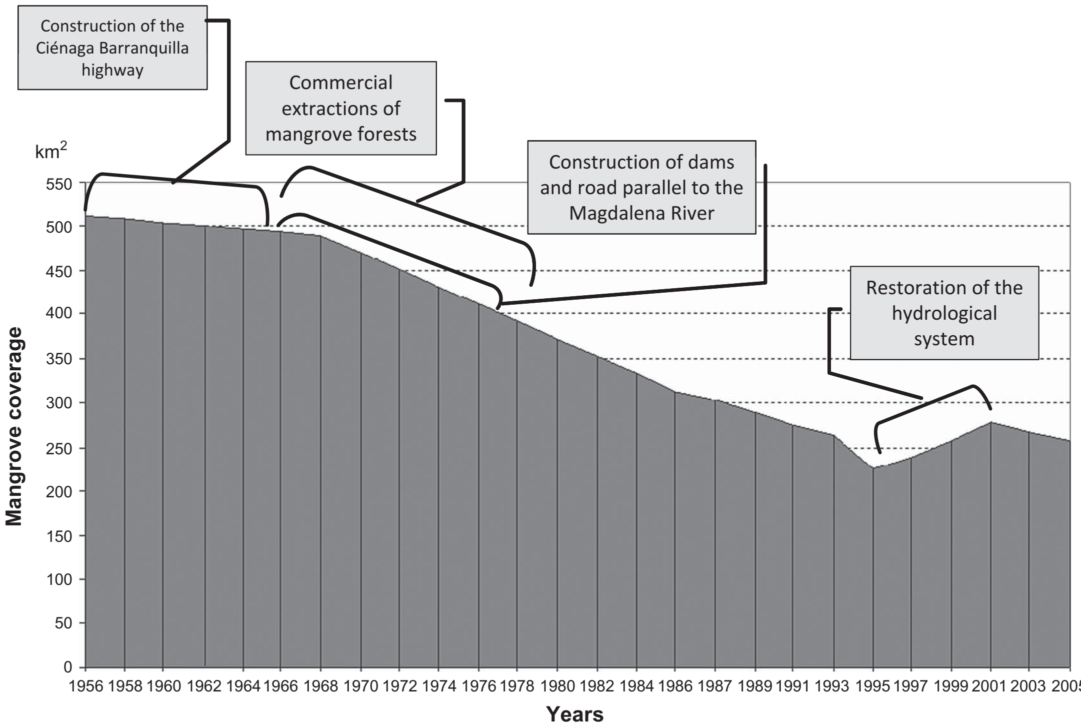

Fig. 3 Evolution of the coverage of mangrove forest during the last 50 years in the CGSM.

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30 000 ha of mangrove in 40 years has been the most visible manifestation of the environmental crisis experienced in the CGSM (Fig. 3). The large-scale demise of mangrove trees in the environmental crisis period has been attributed to two major events: (a) the interruption of hydrological connections with the sea after the construction of the Ciénaga-Barranquilla highway between 1956 and 1964; and (b) the interruption of hydrological flows from the Magdalena River as a consequence of the development projects during the 1960s and 1970s on the right margin of the Magdalena alluvial floodplain (PROCIÉNAGA 1995, Botero and Mancera-Pineda 1996, Garay *et al.* 2004). It is also necessary to recognize that the commercial extraction of mangrove wood occurred in the area for nearly 20 years and aggravated the mangrove forest crisis (Hernández *et al.* 1980).

A scarcity of water and the loss of forest cover exposed several water bodies to sunlight and wind. These exposed areas became evaporitic salt flats (Bernal and Betancur 1996). Increased saline stress (Table 1) caused a sharp decrease in the ability of mangroves to produce and disperse propagules. The rates of tree mortality increased from 179 ha year^{-1} between 1956 and 1968 to 984 ha year^{-1} between 1968 and 1987. These rates reached 1930 ha year^{-1} in 1994–1995 (INVEMAR 2005, Rivera-Monroy *et al*. 2006). Beginning in 1996, restoration activities allowed the mangrove forest to recover slowly until 2001, when 27 800 new ha of mangrove were recorded (INVEMAR 2005). However, new symptoms of mangrove degradation, such as defoliation and dead trees, subsequently began to appear, particularly around Caño Clarín, with mangrove coverage decreasing at a rate of 505 ha year^{-1} until 2005 (INVEMAR 2005). These new losses were probably related to a reduction in the amount of water entering the system, a consequence of the lack of hydraulic infrastructure maintenance. The ecological history of the mangrove forest in the CGSM is presented in more detail in Appendix A.

Local fisheries Historically, the CGSM has been very important for fishing and has produced large catches of molluscs, crustacean and fish. Between 1970 and 1975, the harvest from the CGSM represented 70% of the total hydrobiological resources of the Caribbean coast of Colombia. This harvest met the local demand and supplied markets in the neighbouring coastal cities and inland areas (PROCIÉNAGA 1995). Additionally, in 1994, the artisanal fishery at CGSM was one of the most important in Colombia, with 3500 fishermen, 1300 canoes and a catch of 5334 t. The fishery contributed to more than 60% of the country's landings from the

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Caribbean coast in the same year (Santos-Martínez and Viloria 1998).

However, from the late 1980s to the mid-1990s, the fish biomass and the fish diversity were reduced by 70% and 35%, respectively. In fact, during the 1990s the fish assemblage in the CGSM was dominated by only a few species (*Eugerres plumieri*, *Diapterus rhombeus*, *Micropogonias furnieri*, *Mugil incilis*, *Cathorops spixii*, *Elops saurus,* and *Anchovia clupeoides*) (Rueda and Defeo 2003a). Moreover, these species were overexploited (INVEMAR 1995). This severe change resulted from the degradation of the mangrove forests. Mangroves are an important refuge and nursery habitat for fish and shellfish fauna and they may serve as sinks of inorganic nitrogen and phosphorus, thereby preventing eutrophication of the water bodies in the CGSM (Mancera and Vidal 1994, Botero and Mancera-Pineda 1996, Botero and Salzwedel 1999). The source of most of the organic nutrients that threatened the water quality of the CGSM was the fertiliser input from the monocultures that expanded in the watersheds of the area during the environmental crisis period (see above). During the period 1995–1997, the eutrophic conditions and low oxygen concentrations caused several fish kills (Botero and Salzwedel 1999).

Furthermore, the severe environmental degradation of the system further aggravated the impoverishment of the local human population. The local fishermen responded by exerting more pressure on the fisheries. They modified their fishing nets and progressively reduced the mesh size. The intensive use of mesh sizes smaller than 2.5 in. (6.35 cm) greatly affected the four target species, *E. plumieri*, *M. incilis*, *C. mapale*, and *Ariopsis* sp. (Table 2).

Table 2 Size at capture of the most important fish species in the CGSM, showing the percentage of the catch below the mean maturity size (MMS) (based on Narvaez *et al*. 2008).

Species	MMS (cm)	Years	Catch size		Catch below MMS (%)
			Min (cm)	Max (cm)	
Mugil incilis	25.7	1994–1996	5.5	39.0	70
		2000–2004	9.0	49.0	83
Eugerres plumieri	20.0	1994–1996	9.0	45.5	47
		2000–2004	14.4	42.5	30
Cathorops mapale	23.0	1994–1996	9.5	31.0	90
		2000–2004	7.0	29.5	88
Ariopsis sp.	41.0	1994–1996	16.0	50.0	98
		2000–2004	13.5	46.0	99

The resulting increase in fishing mortality impacted the nursery function of the coastal wetlands (Santos-Martínez and Viloria 1998, Rueda and Defeo 2003b, Narvaez *et al*. 2008).

The reestablishment of freshwater flows after the reconnection of the Magdalena River to the lagoon complex in 1996 resulted in important changes in the salinity regime and in the sedimentation rates (Table 1). These changes influenced the structure and the composition of the shellfish and fish communities (Fig. 4). One of the most serious effects that occurred was a reduction of 95% in the populations of oyster (*Crassotrea rhizophorae*) during 1995–1996, one of the most valuable commercially exploited resources of the CGSM. As a consequence of this drastic reduction, oyster catches decreased by 57% from 1995 to 1996. The associated decrease in the income of the fishermen was 18% (INVEMAR 2001, 2003, 2004, 2005) (Fig. 4).

Finally, the composition of the fish assemblage changed during the post-restoration period. The catches of estuarine fish increased to 64% of the total catch in 2005 and the catches of molluscs and crustaceans increased to 22% of the total catches. Compared to the harvest level in 1994, current captures have decreased 41% in volume and the average income of the fisherman has decreased by 35% (Fig. 4). This situation has increased the poverty rates in the local villages that are relatively dependent on fishing. Appendix A summarizes the main events that mark the recent history of the fisheries in the CGSM.

The ecosystem services provided by the CGSM eco-region

The experts attending the workshop and the individuals interviewed identified 28 ecosystem services (Table 3). Of this total, 50% were classified as provisioning, 18% regulating, and 32% cultural services. The results of semi-structured interviews showed that 46% of these ecosystem services had decreased. Provisioning services, with a decrease of 59%, represented the most critical of these categories. Of all the ecosystem services identified, 46% of the provisioning services, 50% of the regulating services, and 55% of the cultural services were considered essential for maintaining the respondents' well-being. Figure 5 identifies the most critical ecosystem services by showing the historical trends and the importance of these ecosystem services for local well-being

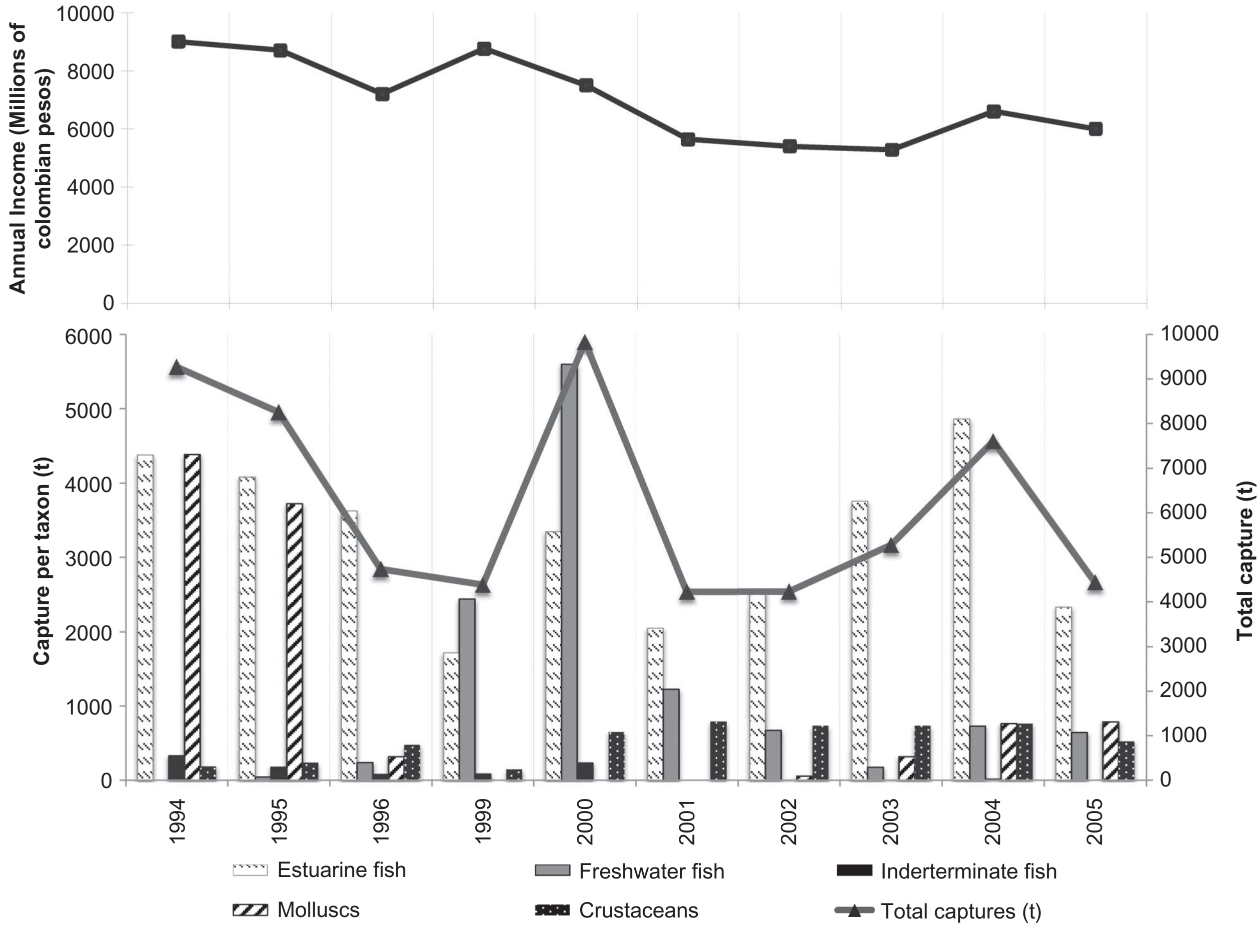

Fig. 4 Relationship between the annual catches and the annual income of fishermen (data source: INVEMAR 2005).

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as perceived by the respondents. From this perspective, seven provisioning services (including fishing, shellfishing, agriculture, water and medicinal plants), the mangroves' nursery function for fish, and two cultural services had the highest levels of deterioration and of importance for the well-being of the local people. The services thus identified were therefore the most critical ecosystem services to address. We also found a weak association between those provisioning and cultural services considered as essential for maintaining local well-being and those that had tended to deteriorate (provisioning: $\chi^2 = 10.6$, $p < 0.1$; cultural: $\chi^2 = 2.7, p < 0.1$).

IMPLICATIONS FOR MANAGEMENT AND ADAPTIVE GOVERNANCE

To develop sound environmental management strategies, it is important to review the associated social-ecological history to understand the complex linkages among historical drivers of change, trends in ecosystem services and human well-being (MEA 2005).

It appears that the downward trends exhibited by some ecosystem services perceived as critical by stakeholders at the CGSM are the result of synergistic interactions among several historical factors: changes in the hydrological regime; loss of mangrove forests; and fishery overharvesting. For example, a general decrease in the income of fishermen is directly related to a shortage in fish abundance throughout the lagoon complex, as well as to decreases in artisanal fisheries yields. These effects are also related to the general degradation of water quality and the loss of mangrove coverage. The strong dependence of local communities on basic ecosystem services provided by the CGSM, such as fishing and shellfishing, for their livelihood and health has made these communities highly vulnerable to uncertainties associated with natural and anthropogenic disturbances. Moreover, the human well-being of communities living in the CGSM also depends on other ecosystem services (Table 4), including drinkable water, traditional uses of fauna and flora and several cultural services (see Fig. 5).

Table 3 List of the ecosystem services identified and the effects of the historical changes in hydrological dynamics, mangrove coverage and fishing on ecosystem services delivery (* = indirect effect).

Ecosystem service type	Ecosystem service	Specific ecosystem service	Relationship with changes in		
			Hydrological dynamics	Mangrove coverage	Fish communities
Provisioning	Food	Aquaculture	-	-	×*
		Agriculture	×	×*	-
		Cattle	×	-	-
		Hunting	×*	×	-
		Fishing	×	×	×
		Shellfishing	×	×	×
	Drinkable water		×	-	-
	Forest resources	Fuel	×*	×	-
		Wood and timber	×*	×	-
	Vegetation-related	Medicinal plants	×*	×	-
		Ornamental use	×*	×	-
	Animal-related	Pets	-	×*	-
		Medicinal use	×*	×*	×
		Ornamental use	-	×*	×
Cultural	Educational	Environmental education	×	×	×
		Scientific values	×	×	×
		Local ecological knowledge (LEK)	×	×	×
	Recreational	Aesthetic value	×	×	-
		Nature tourism	×	×	-
		Relaxation	×	×	-
	Local identity	Spiritual values	-	×	×*
		Cultural heritage	-	-	×
		Sense of place	×	×	×
Regulating	Climate regulation		×	×	-
	Air quality		-	×	-
	Soil formation and fertility		×	×	-
	Hydrological regulation		×	×	-
	Nursery	Habitat conservation	×	×	-

When local users are dependent on a resource (e.g. fish are necessary for local fishers to earn their livelihoods), the appropriators have an immediate stake in the fate of the resource base. This situation amounts to an incentive for users to protect natural resources from overharvesting (Gibson *et al.* 2000). If a necessary resource becomes or is perceived to become scarce, the incentive for collective action is high, as long as the resource is not degraded beyond the point of feasible improvement (Heltberg 2001). In our case study, local users are strongly dependent on provisioning services for their livelihood, so collective action could be a key management strategy. However, the current situation in the CGSM suggests that local users do not have the ability to undertake collective action because of the historical failure of government policies (Botero and Salzwedel 1999) fostered by the Colombian armed conflict (Vilardy and Renán-Rodríguez 2011).

In this context, reinforcing social capital through rebuilding local institutions seems critical for improving environmental governance in the CGSM. Given the complexity of the social-ecological dynamics in this area, working partnerships should be built between management agencies and ecosystem services users. These partnerships should promote participation and responsible sharing by multiple stakeholders from the initial stages of the planning process to the final stage of decision making.

Achievement of this goal entails the sharing of management power and responsibility through multiple institutional linkages involving both horizontal and vertical cross-scale interactions. These interactions would therefore involve government agencies,

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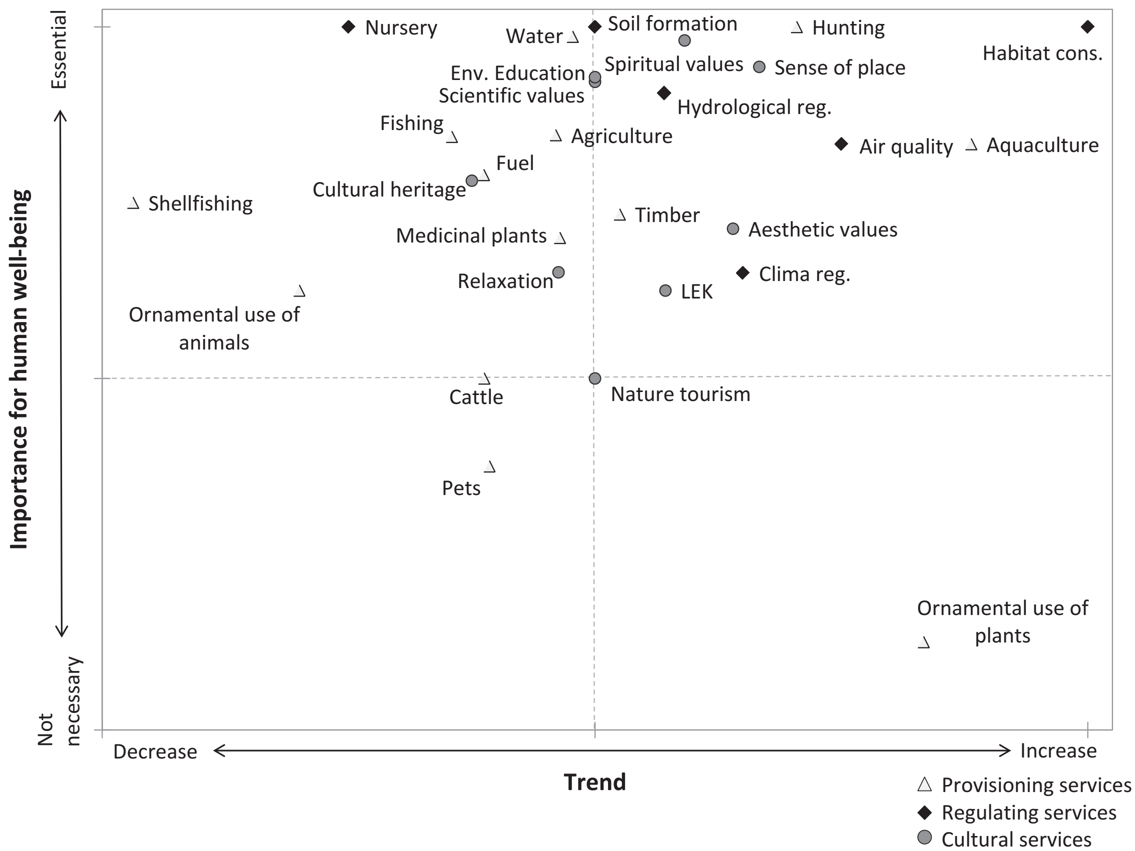

Fig. 5 Scatterplot of the historical trends in ecosystem services delivery (*x*-axis) and their importance for maintaining human well-being (*y*-axis), according to respondents. The *x*- and *y*-axes represent the ranking of ecosystem services according to these variables.

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Table 4 Relationships between ecosystem services delivered by the CGSM and human basic needs. The classification of basic and social needs follows Max-Neef (1992).

Basic needs	Ecosystem services
Individual needs:	
Subsistence	Fishing
	Drinkable water
Protection	Coastal protection against storms
	Hydrological regulation
Affection	Sense of place
	Spiritual values
Social needs:	
Participation and knowledge	Environmental education
	Local ecological knowledge
	Scientific research
Recreation	Aesthetic values
	Nature tourism
	Relaxation
Social identity	Cultural heritage
	Sense of place
	Traditional uses of wild fauna and vegetation
	Scientific research
Freedom of choice	Spiritual values
	Environmental education

NGOs, local communities and user groups. To establish an appropriate foundation for these processes, the development of new institutional frameworks for adaptive governance will be needed.

Finally, this study demonstrates the scientific necessity for recognising the complex links between ecological and social systems. Such recognition should be based upon more holistic and interdisciplinary frameworks to incorporate information about these links into the environmental decision-making process.

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