SOCIO-ECONOMIC AND ECOLOGICAL FEEDBACKS IN LAGOON FISHERIES: MANAGEMENT PRINCIPLES FOR A CO-EVOLUTIONARY SETTING

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This paper explores management issues that arise in a coastal lagoon fishery in light of the significant interrelationships between the lagoon ecosystem and the socio-economic developments of the local communities. In particular, we review the major socio-economic evolutionary events in a network of communities surrounding a lagoon, and trace their impacts on both the lagoon's goods and services and stakeholders' well-being. Of interest is how stakeholders may respond to manage the lagoon sustainably as development pressures, technologies, and social systems continue to evolve.

The recent shift in natural resource and environmental management theory from a 'biological-centered approach' to a 'social-ecological approach' (Jasanoff *et al*., 1997; Kates *et al*., 2001) and from a single population approach to a system dynamics approach, particularly a complex systems approach (Kauffman, 1993; Levin, 1999), creates a need for studies that analyze the dynamic interrelationship between natural and social systems. This is because, in order to propose or reformulate management rules and policies to achieve the ultimate goals of resource sustainability, efficiency, and social justice, natural resource managers must understand how ecological and socio-economic systems interconnect and change over time as they constantly co-evolve. For this purpose, concepts from complex systems analysis and from ecological economics are important to consider, as they are clearly reflected in the Lisbon principles on which this paper will base its resource management proposals.

The dynamics of integrated social and ecological systems may be analyzed through the lens of complex systems thinking. This approach sheds light on the complex nature of several management problems. Complex systems thinking acknowledges the non-linear nature of system dynamics, the uncertainty intrinsic in any system, the problem of scale, and systems' capacity of self-organization, among other attributes (Costanza *et al*., 1993; Kauffman, 1993; Levin, 1999).

To deal with the complex nature of social-ecological systems, some scholars have advocated the adaptive management approach (Holling, 1978; Walters, 1986). In this type of resource management, managers must constantly respond to ongoing changes in ecological systems caused by either 'human-made' or natural disturbances. Because disturbances are inevitable, management must always be adaptive (Gunderson *et al*., 1995). The adaptive capacity of a social-ecological system may be defined as its ability to respond to changes and disturbances without losing options for the future (Resilience Alliance, 2003). In order to be adaptive, a management system should be flexible, diverse and capable of learning and adapting (Folke *et al*., 2002; Berkes *et al*., 2003).

Ecological economists investigate co-evolutionary processes between environment, technology, knowledge, institutions and values, to develop tools that are able to promote sustainable governance of resources (Constanza *et al*., 1997). This school of thought acknowledges that "human preferences, understanding, technology and cultural organization all co-evolve to reflect broad ecological opportunities and constraints" (Costanza *et al*., 1997, p.337). The earth is seen as materially finite and a closed system; hence, technical advances do not create new resources (i.e., human-made capital is a complement to rather than a substitute for natural capital; Daly, 1977). Surprises and uncertainty are considered part of any ecosystem although they may have exogenous origins (Holling, 1986). Ecological economics further acknowledges that "community relations define who people are, affect what they want, [and] facilitate collective action" (Costanza *et al*., 1997, p.24).

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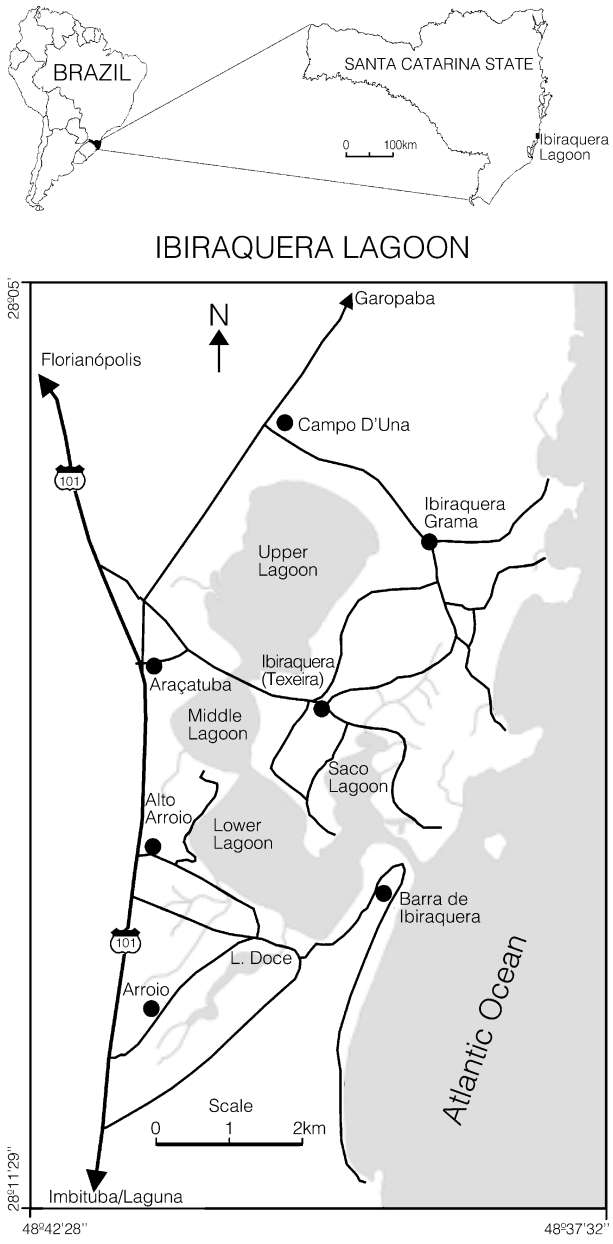

Figure 1. Map of the Ibiraquera Lagoon, Santa Catarina State, Brazil.

Ecological economists advocate that six principles, known as the Lisbon principles, be applied when formulating policies to promote sustainable governance of oceans and coastal areas (Costanza *et al*., 1998, 1999). The first Lisbon principle asserts that entities (individuals or corporations) who use environmental resources are responsible for doing so in an ecologically sustainable, economically efficient and socially just manner (responsibility principle). Under the second Lisbon principle, the power to make resource management decisions should rest with the scale of governance that has the most relevant ecological information, which considers ownership and actors, and which internalizes costs and benefits (scale-matching principle). According to the third Lisbon principle, uncertainty about potentially irreversible environment impacts must be taken into account (precautionary principle). The fourth principle calls for continuous monitoring of social, economic and ecological information because resource management systems are dynamic (adaptive management principle). The fifth principle requires identification and allocation of all internal and external costs and benefits (social and ecological) of alternative uses of environmental resources (full cost allocation principle). Finally, under the sixth Lisbon principle, stakeholders should participate in the formulation and implementation of decisions about environmental resources (participation principle).

Because two-thirds of the world's population lives in coastal areas and human welfare is highly dependent on the oceans (Costanza *et al*., 1999) disruption of coastal ecosystems poses a major threat to both oceans (Antunes and Santos, 1999) and humans. Hence, appropriate governance of coastal areas and management of coastal resources must be a high priority for any state with coastal area. Ideally, effort shall be made to promote sustainable governance of coastal areas at the global scale. However, such global effort can be very costly in terms of both time and money. Actions taken locally are more likely to be effective in the short run (Johnson and Duchin, 2000) as "local level institutions are generally better able to identify the recipients of both costs and benefits and assign responsibilities that internalize both" (Costanza *et al*., 1999, p.183).

In this context, this paper examines the management strengths and shortcomings of a coastal fishery ecosystem, focusing on the co-evolution of local communities at the Ibiraquera Lagoon, located in southern Brazil. This area is a micro-watershed where most environmental impacts are locally generated and can be locally addressed, although lagoon problems may be exported to the ocean and vice-versa. The Lisbon principles (Costanza *et al*., 1999) incorporate conceptual underpinnings of systems analysis and ecological economics, and, as such, offer a sound basis for proposing management solutions. Thus, in the end, the paper draws conclusions about an appropriate approach to managing a system such as the Ibiraquera Lagoon for ecosystem sustainability based on these Lisbon principles (Costanza *et al*., 1999).

Description of the Lagoon

The Ibiraquera Lagoon, in the municipality of Imbituba (pop. 33000 in 1991), Santa Catarina State, is located along the southern part of the Brazilian coast, and is surrounded by seven communities (Figure 1). Despite the development of the city of Imbituba in the first half of the 20th century, most of the Ibiraquera region, including the seven communities around the lagoon, remained quite isolated until the 1960s. Residents of the communities lived off household agriculture and subsistence fishing. Many socio-economic and ecological changes have occurred since then, as will be discussed throughout this paper. By 2000, tourism-related activities dominated the economies of most of the communities. However, fishing continues to be integral to the communities, serving as an important source of cash or in-kind income for households in the area.

The lagoon itself is shallow (0.20m to 2.0m deep, with isolated 4m deep areas) with a sandy bottom and brackish water. Its 900ha are comprised of four interconnected small basins: Lagõa de Cima, Lagõa do Meio, Lagõa de Baixo, and Lagõa do Saco ('Upper Lagoon', 'Middle Lagoon', 'Lower Lagoon', and 'Saco Lagoon'). The lagoon receives its freshwater input through rainfall and at least nine springs.

Through most of the year, a sandbar separates the lagoon from the Atlantic Ocean. If there is no human intervention, a channel bursts through the sandbar once sufficient water pressure builds, and the lagoon's water level drops through natural processes. However, human actions to serve management purposes more often cause channel openings in the sandbar. Either way, the channel eventually closes through sand deposition by ocean currents and tides, which in turn allows the lagoon's water level to increase once again.

Pink shrimp (*Farfantepenaeus paulensis* and *F. brasiliensis*) and mullet (*Mugil platanus, Mugil* spp.) are the main fishing resources in the area. Of these, shrimp is the more valuable and commercialized. Mullet is seldom sold.

Local fishers also catch blue crab (*Callinectes* spp.) for domestic consumption.

Lagoon shrimp and fish stocks are heavily influenced by the timing and duration of channel openings and by fishing activities. Because their timing affects the diversity of species in the lagoon, channel openings have been managed in order to allow the entry of fish and shrimp stocks moving through the ocean in front of the channel. The spring months are a major recruitment time for shrimp at the Ibiraquera Lagoon, with the fall months representing a second, less important recruitment period. Channel openings create opportunities for fish and shrimp not only to enter but also to leave the lagoon, so their duration is critical. Lengthy channel openings may allow a mullet school in spawning migration not only to enter but also to leave the lagoon, while channel openings that are too short may accomplish insufficient stock renewal as too few fish or shrimp enter. Finally, harvesting small fish and shrimp reduces the potential future harvest of larger (better-priced) fish and shrimp and threatens the sustainability of the lagoon fishery system. While all fisheries are subject to this effect, a temporarily closed system such as the Ibiraquera Lagoon is particularly susceptible to it.

Methods

Fieldwork completed during June 1999 through May 2000 provided most of the data for this study. Methods included structured and semi-structured interviews with key informants and small groups, archival research to trace changes in fisheries legislation and the local socio-economic system, participant observation of fishing activities and the roles and interactions of stakeholders, and collection of data on types and quantities of fish and shrimp harvested and marketed. Interviews elicited information about fishery activities (resources, gears and purposes), the local fish and shrimp market, and the main changes in the local socio-economic and ecological systems over the last five decades and their consequences for the ecosystem and stakeholders' well-being. Combined, these methods generated a rich body of information about how the lagoon area has developed over the last five decades, and how management practices have evolved in relation to conditions in the natural and socio-economic systems.

Evolution of Lagoon Management

The communities around the Ibiraquera Lagoon experienced major socio-economic changes over the second half of the 20th century. While each community had its own particularities, the overall picture for the area shows that the local economy moved from subsistence agriculture and fishing during the 1950s to a mix of agriculture and small-scale commercial fishing during the 70s and to tourism-related activities during the 90s. The main forces driving these changes were infrastructural improvements in the form of road construction and the provision of electricity. Additionally, the region's proximity to the ocean served to boost tourism. This section describes how lagoon management practices responded over this time period to both socio-economic changes and ecological conditions of the lagoon.

Throughout the 1950s and the early 60s, four of the seven communities around the lagoon had no road access to other localities, none had electricity, five of the seven had no general store, and none had a fish store. The region was sparsely populated, with relatively few though large families (often 10 or more children) residing around the lagoon. Transport of people and goods among some communities was usually by pole canoe along the lagoon or by ox and cart along trails. Household-level agriculture was the main source of income for most families, and fishing was mainly for subsistence with fish and shrimp supplying most animal protein in the local diet. There were no local employment opportunities for young people who often migrated to big cities for work. By 2000, the local economy was fully integrated into the regional economy and had become significantly influenced by the latter. All seven communities around the lagoon were fully accessible by road, all shops and households had electricity, there was an active local shrimp market (Seixas and Troutt, 2003), tourists flocked to the area, and environmental problems and challenges had emerged in and around the lagoon. Local population had increased substantially, up to 5000 by 2000 (Seixas, 2002) despite reduced family size, due to tourism growth, which continues to draw new residents hoping to open tourism-related businesses. The population included some 350 professional (licensed) fishers, a few recreational (licensed) fishers, and several unlicensed fishers.

During the 1950s and 60s, the main fishing strategies in the lagoon included the use of cast-nets and gillnets (used as setting-nets, encircling-nets or seine-nets) to catch fish, and cast-nets with kerosene lamps to catch shrimp. Although the local fishers' organization (*Colônia de Pescadores*) and a federal government fishery agency (*Divisão de Caça e Pesca* (DCP) replaced by *Superintendência do Desenvolvimento da Pesca* (SUDEPE) in 1962) already existed, they did not play any important role in the local management of the Ibiraquera Lagoon. *Colônia de Pescadores* was responsible for helping fishers to get their fishing licenses and to take fishers' complaints to the state fishery agency (*Departamento Estadual de Caça e Pesca*); but *Colônia* had no power in decision-making or enforcing fisheries regulations. Federal government regulations concerning access rules and technological limitations were very general and hardly enforced in small-scale fisheries. Hence, local rules and traditional practices were sufficient to manage the lagoon fisheries.

Fishers interviewed in this study recalled that they enjoyed good harvests of mainly large fish and shrimp during these decades. They cite four reasons for this. First, the two main fishing gears, gillnet and cast-net, were made of natural fibers which limited their mesh to large size. Second, relatively few families lived around and fished from the lagoon (i.e., low use). Third, fishing was mainly a part-time activity engaged in for subsistence purposes only. Fourth, fishers respected the practices and rules of long-term fishers regarding where, when and how to fish or not to fish (i.e., the traditional management system).

Socio-economic changes during the late 1960s and the 70s brought several periods of resource over-exploitation. Two main factors were responsible for these periods of over-harvest: technological improvements and road construction which led to the emergence of markets for lagoon fish and shrimp (Seixas and Troutt, 2003).

First, technological innovations in fishing gears and strategies resulted in more efficient fishing. The improved gear included monofilament nylon nets, smaller mesh-size nets, and butane gas lamps which attracted significantly more shrimp than kerosene lamps. A new strategy was the use of gillnets as beach seines along the lagoon shore. As a result of the introduction of these gears and strategies, fishers harvested larger quantities of, albeit smaller, fish and shrimp, in a shorter time. Fishers also spent less time fixing or making nets, as nylon nets were more durable than natural fiber nets. These technological innovations also intensified the frequency and gravity of conflicts over resource access between the two major user groups, gill-netters (low in number but highly efficient) and cast-netters (numerous but less efficient).

Such conflicts had existed for decades but were often expressed as complaints with few episodes of physical confrontation. As technological innovations increased the size and number of gillnets used inside the lagoon, leading to overharvest of the shrimp stock, some physical confrontations occurred. The police were involved in many cases, and some fishers were arrested.

Second, road construction allowed for the emergence of a shrimp market, which shifted fishing activities from subsistence to commercial fishing in response to outsiders' demand for lagoon products. As well, roads brought outside fishers to the lagoon, increasing the number of users harvesting resources. Roads also brought tourists, increasing demand for fish and shrimp. As a shrimp market emerged, profit-oriented fishers started to disregard traditional rules governing access and gears (i.e., how, when, and where to fish) and began to fish in prohibited areas and to use smaller-mesh cast-nets. By the late 70s, all fish and shrimp stocks in the lagoon were caught within about two or three months of channel closure. This meant that there was almost no harvest in the lagoon for several months before the next opening. In contrast, during the 1950s and 60s, lagoon fish and shrimp stocks and harvests continued from one closure until the next opening. During the late 60s and 70s, federal government regulations limited net mesh-size, gillnet length, and types of nets allowed in the lagoon, and rules restricted fishing to certain areas of the lagoon (Seixas, 2002). However, none of these limits or restrictions was effectively enforced.

The declining fish and shrimp stocks, fishers' growing economic dependence on fishing, and conflicts between user-groups that emerged during the 70s triggered several changes in lagoon fishery management during the 80s and early 90s. First, in 1981, a new leader of the local fisher organization was elected who had a high degree of credibility with the local population, and who was willing to promote change. Second, the federal government approved three regulations demanded by local fishers, which reduced fishing effort and led to more equitable resource allocation among fishers. These regulations banned gillnets (1981), the butane gas lamps which were being used with a new fishing gear (a hand-held shrimp tong) to catch small shrimp in their feeding areas (1986), and shrimp cast-nets with mesh smaller than 3.0cm stretched measure (1993). Third, in 1995, the municipal government issued a regulation prohibiting the use of any type of engine; only dugout canoes with poles or paddles were allowed. Fourth, rule enforcement became effective as two state fishery inspectors were stationed in the area. Most of these changes served to improve shrimp and fish stocks and harvests.

Despite the recovery of the lagoon's shrimp and fish stocks, the natural shrimp production became insufficient to supply the local market during the 90s due to increased shrimp demand as tourists, the local population and the number of outside fishers increased. From 1992 to 1998, a shrimp-stocking research project took place in the lagoon, increasing shrimp production considerably; the project introduced shrimp post-larvae, paid for with research funds, to the lagoon (Andreatta *et al*., 1993, 1996). Andreatta *et al*. (1993) estimate shrimp harvests in the first two years of the project to have been 72699kg of pink-shrimp (*F. paulensis*) and 10198kg of white-shrimp (*P. schimitti*). The project improved fishers' welfare (better houses, appliances, etc.) by bringing more money to them as well as to middlemen. Fishers interviewed in the present study said that, once the project was underway, they could catch a lot of shrimp year round, while before the project, shrimp catches during the winter were usually low. However, the project ended due to a lack of funds.

In 1994, the fishery inspector positions were extinguished, probably due to budget constraints. In the absence of local fishery inspectors, the newly implemented rule enforcement structure proved to be ineffective from 1994 to 2000. The resulting arrangement charged a few officers, located in a town 50km away, with enforcing all resources and environmental legislation, including those related to fisheries, in an area that covered several municipalities. As a result, fishers undertook several unregulated fishing activities during this period, including the use of banned gears and new destructive gears. These activities negatively affected shrimp and fish stocks. At the same time, the lagoon fishery system began to experience new challenges from the ongoing increase in the number of tourists, whose sailing and recreational fishing interfered with professional fishing (i.e., fishing carried on by part-time and full-time local fishers). As well, an increase in the number of outside fishers accompanied unregulated growth of summer cottages, guesthouses and restaurants in the area. Excessive development was destroying vegetation on the lagoon edge, which in turn increased erosion, siltation, and mudslides, filling the fish migration channels and destroying fish and shrimp feeding habitat. In addition, drainage of sewage into the lagoon by the large number of tourists and illegal constructions (with poorly constructed septic tanks) began to pollute the lagoon.

The lagoon communities responded to the lack of rule enforcement in various ways. In 1998 a subset of local fishers organized themselves into groups to patrol the Upper Lagoon, but their activities were short-lived and ineffective because they lacked legitimacy. Indeed, they were sometimes threatened with shotguns by fishers using illegal gears. As well, to deal with the impacts of unregulated tourism, three of the seven communities surrounding the lagoon re-activated their community councils in 1999/2000. To tackle the siltation problem, the fisher organization, in cooperation with state and municipal governments, implemented a lagoon dredging project whose results remain uncertain.

The scenario at the end of the 1990s indicated that a new resource crisis was emerging. It is noteworthy, however, that at that time, very few fishers (less than 10 of 350 holding professional licenses) were strictly dependent economically on fishing (full-time fishers). Most local fishers were part-time fishers, working in tourism-related activities, and fishing shrimp at night to supply the local market and supplement their incomes. Most outside fishers were recreational fishers. Consequently, as a fisher stated, if another big production crisis occurred in the lagoon, this crisis would not be as disruptive to fishers' well-being as those of the end of the 60s and 70s, because fishers are now considerably less dependent on fishing. On the other hand, because the lagoon is one of the major attractions of the region, a large disruption in its ecosystem, for instance caused by pollution, would negatively impact tourism activities, and consequently fishers' well-being.

Impacts of Socio-Economic Disturbances on Ecosystem and Stakeholders' Well-being

The Ibiraquera case shows several interactions among the local socio-economic system and lagoon management through a historical perspective. In the following discussion we investigate how the lagoon ecosystem and the local social system were influenced by socio-economic events.

Table I summarizes the impacts of major evolutionary events on the lagoon's goods and services and on stakeholders' well-being over the past five

TABLE I
MAJOR SOCIO-ECONOMIC EVOLUTIONARY EVENTS AND THEIR IMPACTS ON THE LAGOON'S GOODS AND SERVICES AND STAKEHOLDERS' WELL-BEING*

	Major socio-economic evolutionary events				
	Innovation in fishing technologies	Development of shrimp market	Overfishing	New regulations and strong enforcement	Lack of rule enforcement (illegal sewage disposal)
Lagoon's goods & services					
Habitats and species	affected structure and diversity of fishing resource		destroyed nursing habitats	restored habitats	
Nutrient cycling and waste treatment	some gears stir the lagoon bottom disturbing nutrients sedimentation			ban of gears that disturb nutrient sedimentation	potential increase of lagoon eutrophication and risk of fish and shrimp suffocation
Food	capture of more, albeit smaller fish and shrimp	pressure on shrimp stocks and by-catching problems	reduced stocks	restored stocks	pollution and risk of health problems
Transportation				ban of engine vessels avoid water pollution	
Recreation			likely to decrease recreational fishing	ban of engine vessels increased safety in water	risk of health problems by fishing, sailing, and bathing
Culture		disrespect for traditional practices		reduced conflict among user-groups; more just resource allocation	
Stakeholder well-being					
Who won	commercial fishers	commercial fishers; middlemen	in short run: fishers with high rate of time preference in long run: nobody	cast-netters, local people, most tourists	few cheaters (both locals and outsiders)
Who lost	subsistence fishers	subsistence fishers	in short run: unclear in long run: all fishers, middlemen, local people	gill-netters and tourists with jet-skis and engine canoes	most people (both locals and outsiders)

	Lack of rule enforcement(illegal gears and vessels)	Shrimp-stocking project	Lagoon dredging project	Infrastructure improvement (roads, electric power)	Excessive development and tourists boom
Lagoon's goods & services					
Habitats and species	affected structure and diversity of fishing resource	killed shrimp predators (fish) using rotenone, affecting biodiversity	project interruption may affect water circulation and habitats in the Upper basin		destruction of feeding habitats and fish and shrimp migration channels
Nutrient cycling and waste treatment	use of gears that stir the lagoon bottom disturbing nutrients sedimentation	added nutrients to feed captive shrimp interfering with natural cycles	expected to favor water circulation in lagoon and between it and ocean (flushing into ocean)	bridge construction filled a channel interconnecting two basins affecting water circulation	favored increase of illegal sewage disposal; modified sandbar and affected channel openings
Food	capture of small fish and shrimp	enhanced shrimp stocks	expected to increase fish and shrimp migration into the lagoon	favored population growth and large food demand	increased demand for food
Transportation	use of engine vessels polluting water		re-opened channels that facilitate canoe traffic	reduced the use of canoes for transportation	wealthy tourists using jet skis and engine canoes
Recreation	engine vessels put in risk people's safety in the water	enhanced shrimp stocks attracting more recreational fishers	expected to allow better lagoon water flush into the ocean reducing pollution	favored tourism development	increased lagoon scenic value and economic value of surrounding land
Culture		informed fishers about shrimp life-cycle		favored immigration of outsiders who bought new values and behaviors	displaced locals; outsiders' lack of respect to some traditional rules; lack of sense of place
Stakeholder well-being					
Who won	cheat fishers and tourists with jet-skis and engine canoes	all fishers; middlemen	most people (probably)	locals (well-being); tourists	few businessmen and tourists
Who lost	honest fishers, locals and most tourist	unclear	perhaps fishers from the Upper basin	locals (environment and community disruptions)	most locals and tourists

decades. Although fieldwork did not attempt to calculate the monetary costs or benefits of each impact, their positive and negative effects on the ecosystem and stakeholders' well-being are delineated. As presented above, the major evolutionary events in the Ibiraquera region over the period of analysis include innovations in fishing technologies from the late 60s onward; infrastructure improvements such as road construction and electric power availability, especially during the 70s; development of a shrimp market during the 70s; an overfishing crisis in the late 70s; the creation of new fisheries regulations and the establishment of strong rule enforcement structure between 1981 and 1994; the breakdown of the enforcement structure in 1994, leading to illegal sewage disposal into the lagoon and the use of illegal fishing gears and vessels in the ensuing years; the implementation of a shrimp stocking project from 1992 to 1998; the occurrence of a dredging project to reopen the lagoon's silted up channels in 1999; and the excessive and unplanned 'development' of the region due mainly to a tourism boom during the 80s and 90s.

Technological innovations may result in more efficient fishing, but, if not properly used, they may cause overfishing and ecosystem disruption. In addition, technological innovations might promote unfair resource distribution, as some technologies are not affordable to all users. Increasing market demands may lead to increased fishing effort with higher chances of capturing and discharging non-target species (by-catching), which in turn may cause ecosystem disruption. Increasing market demand may also lead to the elevation of fishers' private interests (i.e., profit-maximization) over social goals (e.g., sustainable resource use). Overfishing causes ecosystem disruption and may reduce fishers' and middlemen's welfare in the long-run. As a result, some technological restrictions may prevent overfishing and promote better resource distribution (see next section).

Official regulations based on fishers' ecological knowledge and concerns and an appropriate enforcement system proved to restore the lagoon's structure and dynamics, reduce user-group conflicts, promote more just resource allocation, increase people's safety and avoid pollution. On the other hand, lack of rule enforcement may disrupt ecosystem natural dynamics and lead to overfishing, increase the risk of pollution and human health problems and decrease people's safety on the water. Often, most people bear the cost of the actions of just a few cheaters.

Infrastructure improvements may increase the local population's well-being, but it may also expose the local society to immigrants' social and cultural values. The introduction of different values may cause a breakdown in the local authority system and disruption of social life, resulting in a 'community failure' of resource management (McCay and Jentoft, 1998). Depending on the type of infrastructure 'improvement,' it may either relieve pressure on the ecosystem or exacerbate ecosystem destruction. Excessive, and usually unplanned, development often results in ecosystem degradation, increased pressure on resources, and conflict of interests between outsiders and the local population holding some sense of place. 'Development' projects, such as the shrimp stocking project and the lagoon-dredging project, focus mainly on human benefits, disregarding the side-effects on ecosystem structure and resilience. Some projects may result in positive impacts on the ecosystem; others result in negative impacts. As well, some stakeholders may benefit from development projects, while others may not. Hence, the full range of a project's socio-economic-ecological benefits and costs must be considered *a priori*.

Principles for Management in a Co-evolutionary Setting

Agrawal and Yadama (1997, p.457) suggest that although "socio-economic forces are important in influencing resource management and the condition of renewable resources, … their influences [can] usually [be] mediated through community institutions." The Ibiraquera case shows that in the late 1990s, there was almost no local resource management institution influencing the lagoon system. In fact, the system was being negatively affected by state policies (weak rule enforcement, no access restriction), technological factors (inappropriate fishing gears, development projects), market pressures (high demand for shrimp) and population pressures (large number of local residents, outsiders and tourists).

In order to craft community institutions to mediate the negative effects of such factors and to create social and economic incentives for better lagoon management, we suggest the elaboration and implementation of a new management plan based on the six Lisbon principles. Specifically, we suggest the establishment of an Ibiraquera Lagoon management forum through a co-management process. Co-management is an arrangement in which responsibility for resource management is shared among governments, resource users and other stakeholders. Understanding that fisheries management and environmental policies in Brazil are still quite centralized (top-down approach), attention is called to the idea that government at various political levels may be required to change regulations and create enabling legislation for co-management (Seixas and Berkes, 2004). Indeed, we recognize that these and many other barriers to participatory fisheries management in Brazil identified by Seixas (2004) need to be overcome in order to establish such a forum.

Ideally, the forum should be the ultimate governance authority to manage the lagoon. Furthermore, the scale of the forum's governance should be the lagoon micro-watershed, but the forum should include representatives from municipal, state and federal government agencies because of the stake they have in environmental management in general and because any management decisions over the lagoon and its surrounding may carry effects that are experienced at a variety of scales. The forum may be a long-lasting institution able to deal with the current problems and to actively respond, through an adaptive management approach (Holling, 1978, Walters, 1986), to future socio-economic-ecological problems.

The structure of the forum, the decision-making process and its activities may arise from the local political scenario, but they will all depend on the ability of fishers and other stakeholders to organize themselves, and the willingness of the government to facilitate the process (Seixas and Berkes, 2004). A detailed discussion of how this process may happen considering the natural resources management policy in Brazil is presented elsewhere (Seixas and Berkes, 2004). In the following paragraphs some general guidelines are provided on how the six Lisbon principles may be addressed by the forum and by a new management plan for the lagoon.

The forum should be comprised of representatives from all of the federal, state, and municipal government agencies holding any responsibility for lagoon management and most, if not all, other lagoon stakeholder groups (local fishers, outside fishers, fishers organization, middlemen, local residents, tourists, tourism businessmen, and any NGO that might exist in the area). Some scientists and natural resource managers should also be members of the forum. In designing and implementing management strategies, all parties should be involved in decision-making to increase

the process's transparency and subsequent rules compliance (participation principle).

Non-governmental stakeholders may create one or more local non-governmental organizations (NGOs) or community-based organizations (CBOs) to represent them in this forum. To trigger stakeholder participation in the forum, there is a need to develop environmental education programs to reach them. These programs might use examples from the present case-study to demonstrate that human-made impacts on the lagoon ecosystem and its surroundings emerge later as impacts on humans themselves. That is, the responsibility principle must be realized from the beginning, and a mechanism that indoctrinates the community according to this principle must be implemented very early on.

The forum must ensure that any 'development' project or management regulation that is designed and planned to adhere to three conditions. First, the plan should internalize as many local monetary and non-monetary costs and benefits as possible. Second, people holding local ecological knowledge (e.g., old fishers) should be involved in planning and decision-making. Third, representatives from governments from different political scales should be involved because some costs and benefits may affect other socio-ecological systems (scale-matching principle). Because the long-term impacts of water pollution, deforestation, overfishing and shrimp stocking are uncertain, a cautious approach to management design and implementation should be the rule rather than the exception (precautionary principle). That is, some mechanisms could be developed to incorporate the long-term ecological value of the lagoon ecosystem services and goods into their current prices.

As the Ibiraquera case clearly demonstrates, socio-economic and ecological systems co-evolve in a non-linear, uncertain way. Hence, in designing and implementing any management plan, effort must be made to continuously monitor the social, economic and ecological systems (adaptive management principle). Although it is quite difficult to do so, effort must also be made to identify and allocate all of the internal and external costs and benefits, social and ecological, of alternative management plans (full cost allocation principle).

In upholding these principles, the forum should be able to effectively address at least the major issues of regulating fishing activities and other recreational activities, managing channel openings, mitigating problems arising from sewage systems, garbage dumping, and irregular buildings close to the lagoon margins, and controlling deforestation along the lagoon margins and along springs that drain freshwater into the lagoon. Failure to resolve these issues in a timely and effective manner may threaten the productivity and beauty of the lagoon area as well as the standard of living derived from it in the surrounding communities.

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