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A Multimethodological Approach for the Sustainable Management of Perifluvial Wetlands of the Po River (Italy)

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ABSTRACT / Marginal aquatic systems (wetlands) of the Po River (Italy) have become the target of a renewed interest because of their value for recreation, natural reserves, and deposits of sand. To preserve these sites, wise management must be the objective of local administrations. In this paper a strategy for the sustainable use of 11 wetlands is presented. It uses simple economic analysis and multiple criteria techniques and provides suggestions to promote sustainability in terms of conservation of natural resources, economic self-sufficiency, and minimization of potential conflicts about the use of the wetlands. In the understanding that sustainability is framed in a long-term perspective, stability analysis is also considered and performed by means of loop analysis, a qualitative technique. Conditions for stability are then discussed about management opportunities.

Local projects may provide guidelines for management at larger scales, where tools to put sustainability into practice are lacking. The European Community policy, on the other hand, envisages that much of the responsibility for integrating economic development with environmental protection will rest on local governments, particularly through the planning process (Gibbs 1994). This is the conceptual framework that inspires this work, which deals with perifluvial wetlands and their sustainable use.

During the last 20 years the Po River basin (northern Italy) has been severely impacted by humans. Structural modifications, intensive agriculture, mining, and rapid urban development have caused profound hydrogeological and ecological changes (Viaroli and others 1996). In the middle tract of the Po River there were many wetlands (riverine wetlands; Brinson 1993), both permanent and temporary (oxbows, cane-brakes, bogs, swamps, wet meadows, ponds), but the worsening of environmental conditions has led to a progressive loss of these sites, while the remainings manifest tangible signs of degradation. The main causes for deterioration and disappearance of riverine wetlands in this area are:

- lowering of the ground waters because of the excessive withdrawal of water;
- disposal of solid wastes and discharge of waste waters;
- construction of riverbank protection groins that prevent water exchanges between the river and the surrounding areas;
- destruction of riparian vegetation and its substitution with industrial poplar groves and cash crops;
- extraction of material and processing;
- hunting and introduction of exotic species.

In the Po River basin wetlands have often been viewed as wastelands, and, as such, undervalued, while ecological studies have revealed the importance of these systems in terms of provision of goods and services (Maltby and others 1994, Young 1994), in particular related to maintenance and possible enhancement of environmental quality (Kadlec 1994, Mitsch 1994). Riverine wetlands are ecologically unique. They favor the recharge of ground water, stabilize river banks, supply energy input to the riverine biota, and provide habitats for wildlife (Belsare 1994, Chung 1994). They also are uniquely situated to intercept nutrients coming from the mainland and through their vegetation regulate the access of nutrients to the water (Gopal 1994, Hillbricht-Ilkowska 1995). In parallel with the increasing knowledge on their ecology, wetlands have become the target of a renewed interest. As buffer zones that limit the impact of human activity on the river ecosystem, they enter in many rehabilitation projects (Brix 1994). Yet, studies on valuing ecosystem services and natural capital often focus on wetlands (Costanza and others 1989).

KEY WORDS: Perifluvial wetlands; Sustainability; Multicriteria evaluation; Qualitative modeling; Natural reserves; Nonconsumptive recreation

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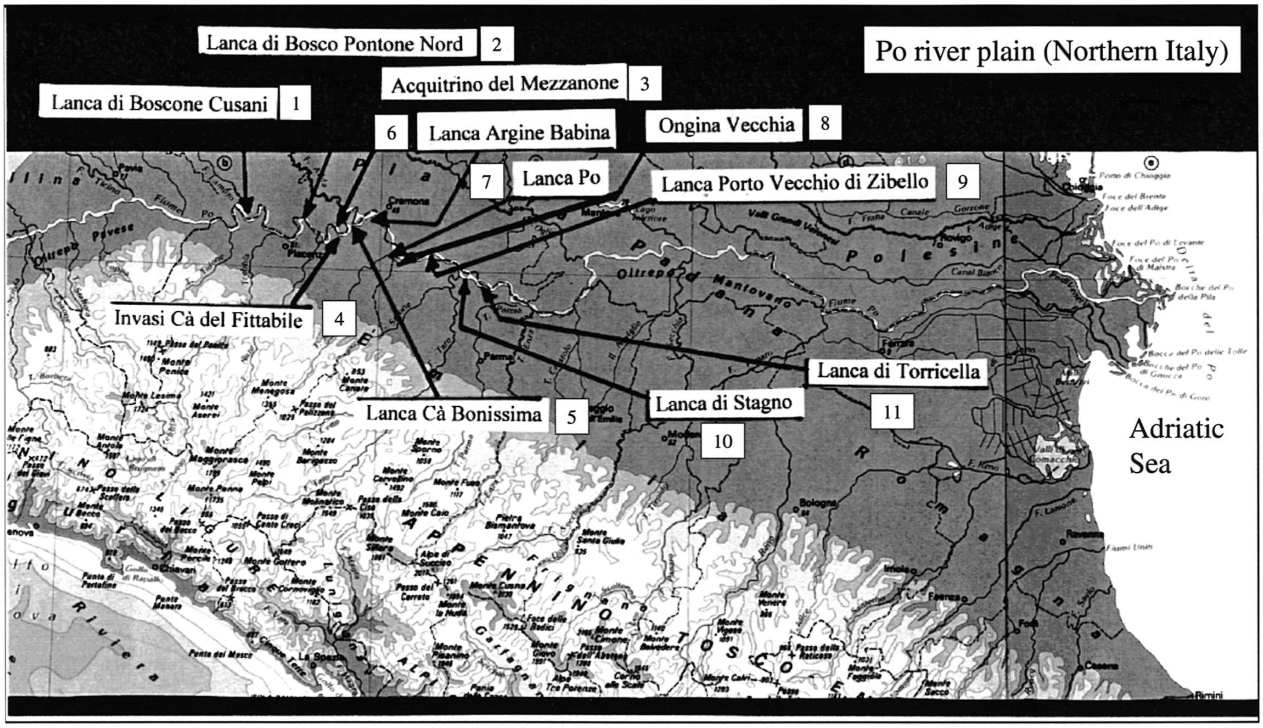

Figure 1. The 11 wetlands identified by location and name along the Po River in the Po plain (northern Italy).

Local administrations (region, provinces, municipalities) are becoming aware that the present tendency to degradation and vanishing of these systems along the Po River must be reversed, but no agreement exists about how to use and manage them. A clear national policy in the context of which local management plans can be formulated does not exist, and different, often conflicting, needs emerge. Some consider wetlands as refugees for wildlife and must remain so, asking for a strong effort of protection. Others think that in managing riverine wetlands respect for nature and ecosystem function can be combined with recreational and educational programs. Yet, as current legislation in Italy prohibits extraction of material from the river bed, the main exploitable deposits of sand and gravel remain confined in perifluvial wetlands. To find optimal management strategies and to minimize conflicts, one must deal with the multidimensional nature of management.

This article reports the conclusions of a pilot study whose aim is to suggest guidelines for the sustainable management of the Po River wetlands. Eleven sites located within the provinces of Piacenza and Parma (northern Italy, see Figure 1) have been the target of investigation. The study has been conducted using different methodologies: multicriteria analysis to define the optimal use for each wetland; simple, preliminary economic analysis to evaluate the economical feasibility of an overall management plan; and qualitative modeling to assess its stability.

Study Area

The Po River basin is the most important in Italy. Its extends over about 70,000 km^2, one-fourth of the entire national territory, and sustains a population of 16 million people. As much as 40% of the entire production of Italy comes from this area, which is also heavily urbanized.

In the trail of the river, which flows throughout the provinces of Piacenza and Parma, most of the soil has been converted to agriculture (corn, wheat, soybean) while spontaneous vegetation is confined to the river banks or on river islands. This area encompasses as many as 34 riparian zones. Of these, 11 wetlands have been selected for this study on the basis of data and documentation at disposal. In particular, attention has been focused on sites that can be of ecological and recreational value because of their landscape features and the species they host (Ammuinistrazione Provinciale di Piacenza 1989). The study area with the 11 wetlands is depicted in Figure 1.

All the selected sites can be classified as river marginal wetlands, per Brinson (1993). Some of them originated from anastomizing river channels or have been the result of the natural meandering of the Po River; others originated from human interventions, such as construction of artificial groins or extraction of material. In what follows only the main morphological characteristics of the 11 sites are described; for details one should refer to Mezzadri and Montanari (1994) and Ricci (1996). Some characteristics of the sites are described in the part concerning multicriteria analysis.

Wetland 1, Lanca Boscone Cusani, originated from the construction of an artificial groin connecting the northern vertex of a long, narrow island to the mainland. Thus, the river branch that separated the island from the mainland is now close at one side, while its mouth remains in connection with the Po River. Wetland 2, Lanca Bosco Pontone, comprises a small body of water that originated from the natural meandering of the Po River. It communicates directly with the main river, although some isolation is provided by a natural sandy groin.

Wetland 3, Acquitrino del Mezzanone, comprises one permanently flooded area and two small temporary bodies of water. It originated from anastomizing river channels, but during the years the connection with the main river has disappeared, and presently the recharge is due to overbank flooding. Wetland 4, Invasi Ca' Fittabile, originated from four sites formerly dedicated to sand extraction and because of this a connection with the Po River does not exist. Wetland 5, Lanca Ca' Bonissima, an old branch of the Po River, is almost completely dry, as the connection with the river is disappearing due to accumulation of sediments of natural and anthropogenic origin. Wetland 6, Lanca Argine Babina, comprises a channel that separates a large, sandy island from the main land. In this site river waters can flow freely into the channel, but an artificial groin obstructs their flow out to the main river. Also in period of low water level (dry season) the recharge is not possible because the channel depth has been reduced due to sediment accumulation.

Wetland 7, Lanca Po, a former branch of the Po River, is now completely separated from the main channel. It is permanently flooded, and its recharge is due mainly to overbank flooding. The Ongina Vecchia, wetland 8, is a former river branch that has taken shape following drainage operations carried out years ago. It is divided into three parts, which rarely exchange water masses between one another.

The oxbow at the Porto vecchio di Zibello (wetland 9) separates a large sandy island from the mainland, but the river branch is suffering from a progressive filling in due to sediment accumulation. Wetland 10, Lanca Stagno, comprises an oxbow that separates an island from the mainland. During the dry season the branch does not receive water because the main river's level remains too low, and the situation is worsening because of the progressive accumulation of sediment. A system of three bodies of water in communication with one another characterizes site 11, Lanca di Torricella. They originated from anastomizing channels, but only one of them has remained in connection with the Po River and provides waters to the others.

Methods

Management Options

A preliminary survey based on field trips and documentation at disposal was conducted to identify critical aspects in terms of needs and priorities and to define management alternatives accordingly. The 11 sites host plants and animals adapted to the typical conditions of the perifluvial environment (Boldreghini 1993, Mezzadri and Montanari 1994). Like islands surrounded by monoculture crops their importance as reserves of biodiversity is noticeable, and preserving them has become an urgent task.

In the last few years these wetlands have been attracting an increasing number of people because of the low-cost recreational opportunities they offer, such as rest, canoeing, and biking (Ricci 1996). Tourism and related activities represent a real opportunity to improve local economy, but to improve the attractiveness of these wetlands environmental quality must be enhanced. In particular attention must be given to water quality, which is poor in most of the sites (Chiaudani and Premazzi 1992, Viaroli and others 1996) and to other forms of degradation, such as hunting, solid waste disposal, intensive agriculture, and introduction of exotic fish (Mezzadri and Montanari 1994).

Extraction of sand may benefit local economy as well. Sand industry in fact is well established in the socioeconomic system of the Po River plain, and new sites for extraction are continuously searched for. The hydrological protection program (Po River Authority 1995), on the other hand, imposes severe restrictions to dredging, which remains possible only in those sites located outside the flooding zone. This area must remain available to waters during overbank flooding, and for each trait of the Po River its extension has been estimated considering historical data on flooding events (Po River Authority 1995). Only 2 out the 11 selected sites fulfill this requirement. They are wetland 4 and wetland 5, Invasi Ca' del Fittabile and Lanca Ca'Bonissima, respectively.

This body of evidence suggests that we consider two main management options. The first recognizes that animal and plant species are precious resources, and their protection requires that any human activity is prohibited except for scientific research and monitoring. This option is called the protection plan. The recreation plan, the second possibility, considers wetlands as areas for tourism development in the framework of nonconsumptive, wildlife-oriented recreation (Duffus and Dearden 1990).

In particular, the recreation plan consists of two parts: (1) reshaping the site's morphology, and (2) providing infrastructures for recreational goals. The first part for all the wetlands consists of placement of vegetation to improve water quality by trapping nutrients and to increase the attractiveness of the site, as well as opening up opportunities for wildlife. Also, in those sites in which water quality has worsened because water circulation is compromised, reshaping must include moderate excavation to restore earlier hydraulic conditions in this respect. Dredging is not necessary in all the sites, nor it can be done in the same way. Essential details about this intervention will be given in the section dedicated to economic analysis because moderate excavation may provide economic return to local administrations.

Parking and picnic areas, walking paths, and biking routes are the minimum structural requirements for recreational activities. Because of the constraints imposed by the law, quarrying may not be considered a true management alternative; nonetheless it can enter in an overall management strategy for the area, as described in the next sections.

A Strategy for Sustainable Management

The two management options privilege nature conservation, as both tend to preserve natural stocks. As such they ensure sustainability from the ecological point of view. To be sustainable, management options must guarantee following generations the same opportunities as today's in terms of access to natural resources. This aspect of sustainability refers here to the possibility of maintaining natural reserves and recreation areas in the long run. Local administrations in the Po River plain suffer from chronic financial problems, and too often insufficient funding becomes the justification for abandoning conservation programs, leaving room to the exploitative use of natural resources. Because of this, creating conditions for economic self-sufficiency must become a priority for any long-term management of the wetlands.

According to this, the proposed strategy for the sustainable management of the 11 perifluvial wetlands considers them as a unit of management in a framework that can be summarized as follows. First, wetlands 4 and 5 would become sites for extraction as they fulfill conditions imposed by the law. In this way, the sand industry can maintain its activity in the area, providing job opportunities to local people and economic return to the municipalities in the form of royalty rent. Royalty rent in turn can be used as economic base for recreation and conservation projects in the remaining nine wetlands. Royalty rent from excavation aimed at reshaping some of the sites can be used as well.

To decide whether one wetland should host a natural reserve or a recreation area, implementation and maintenance costs are estimated for each site in both instances. Then the 11 wetlands are compared in two multicriteria schemes: one in the framework of protection, and the other in the framework of recreation. Although sites 4 and 5 are for quarrying purposes, their inclusion in the multiple-criteria analysis is justified by the possibility that they could be highly suitable for a different use. In such case, a conflict about their destination would arise. The results of multicriteria analysis are used in combination with economic analysis to take a decision about the optimal destination for each wetland.

Economic self-sufficiency guarantees the feasibility of the management plan, and the stability of the mechanism producing economic return is important for the persistence in the long term of natural reserves and recreation sites. Such mechanism is the result of interacting variables, and external events may act on them, altering the overall performance of the system. Stability analysis is conducted as the final step to reveal critical aspects of the system that can affect the sustainability of the management plan.

Economic Analysis

Royalty rent from quarrying in sites dedicated to excavation (4 and 5) is calculated considering that:

- for each site only half the area can be exploited;
- the mean depth of the sand pit must be equal to 4 m. Such a precautionary value reduces to less than 10% the total volume of the hypolimnion of the remaining body of water, reducing the risk of anoxic crises (Viaroli and others 1996). This value, multiplied by the surface of the exploitable area yields the potential extractable reserve (in m^3);
- in general about 10% of the extracted material is lost, partially because it is of low quality and partially because it is washed away during operational works (Guidotti Sand Company, personal communication);
- royalty rent is equal to 15,000 Italian lire per ton (L/t).

The calculation is easily performed by multiplying the potential extractable reserve by the density of the material (roughly 0.13 t / m^3) and the resulting quantity reduced by 10%. This amount is then multiplied by the price imposed by the local administrations. Royalty rent from sites 4 and 5 would yield 16,679 million L to municipalities.

The creation of a natural reserve does not cost much as no intervention is planned to restore environmental quality in those sites. This is justified by the fact that only wetlands that are not severely degraded will occupy the best positions in the multicriteria scheme, and good environmental conditions will be restored simply by prohibiting human access. Thus, the only financial requirement for natural reserves is for surveillance. Given the limited extension of these sites maintenance staff includes two park rangers for a yearly cost of about 44 million L each wetland (Comune di Zibello 1991).

To establish a recreation area a common strategy of intervention has been identified for the nine wetlands and includes:

- reintroduction of floating and submerged indigenous plants, such as *Trapa natans, Nymphaea alba, Nuphar luteum, Myrophillum spicatum, Polygonum amphibius*, and *Nyphoides peltata*. Estimated cost of about 7.7 million L each site.
- plantation of riparian plants typical of the Po River plain (*Populus* sp, *Ulmus minor, Salix alba, Alnus glutinosa, Fraxinus* sp.) along the border of the water body (25 ind / 100 m^2 with a total cost of 4,460 L / m^2, inclusive of purchasing plants, preparation of the soils, addition of organic fertilizer) and reconstruction of the same plant community structure in the area near the wetland for an extension of at least 1000 m^2 (23 individuals / 100 m^2) each site. The total cost for each site is equal to 50.6 million L.
- placement of shrub species, such as *Crataegus monogyna* and other local varieties. Considering for each site a surface of 500 m^2 the cost is 9.9 million L.

Costs for infrastructures must be considered as well. Minimum requirements for each wetland are:

- walking path for bird watching and sightseeing. Cost: 5.06 million L
- parking area 600 m^2 made of material extracted from sites 4 and 5 or locally during reshaping operations. Cost is fairly low, equal to 900,000 L
- picnic area that comprises 10 barbecue areas, 10 tables, 30 benches, and 20 garbage trashes. Cost: 25.3 million L
- maintenance of green areas and surveillance require at least four people each wetland per year, with a cost of 77 million L / year

Costs are estimated on information provided by the Chamber of Commerce, Industry and Agriculture (1995).

Moderate dredging is needed in some sites to promote better water circulation. Further return as royalty rent can be obtained. As dredging may cause some impact on the sites, criteria to limit adverse consequences must be defined. In particular, dredging must be activated only in those situations in which water circulation is or can be (in the near future) heavily compromised; yet mitigation of impacts must be put into practice through best available technology and timing of operational works. For each wetland essential notes about this intervention are given here, while detailed information is provided by Ricci (1996), Viaroli and others (1996), Aministrazione Provinciale di Parma (1994), and Comune di Sissa (1990). Dredging, on the other hand, may cause some impact to the sites.

Wetlands 1 and 2 need no intervention as their connection with the Po River is active and water circulation guaranteed. In wetland 3 water recharge must rely on overbank flooding as the construction of an artificial canal to connect the site with the Po River would give rise to several hydrological problems due to the distance that separates the wetland from the main channel. However, reshaping is necessary to improve water circulation, and it may take the form of a connection between the three water bodies that form the wetland. In wetland 6 moderate excavation is needed to enlarge the branch through which river waters feed the site. Also, its depth must be augmented.

To ameliorate water circulation in wetland 7 the construction of an artificial canal to reestablish the former connection with the Po River is possible, while in wetland 8 reshaping consists of creating an artificial canal through which the three existing water bodies can exchange water with one another. The remaining three wetlands, 9, 10, and 11, are suffering from progressive filling in that impedes sufficient water circulation. The idea here is to enlarge and deepen the channels that provide the connection with the Po River.

Through comparison of royalty rent obtained from reshaping intervention and cost for implementing recreational sites a net value for each wetland is calculated. A positive net value means that royalty rent is more than enough to compensate for implementation cost. The net value will be used in combination with result of

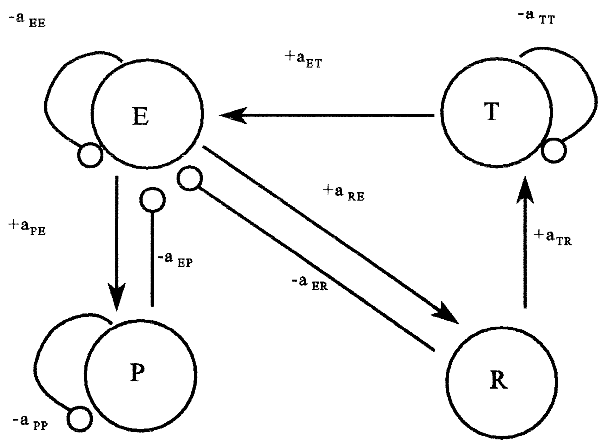

Figure 2. Signed-digraph that depicts main relationships between system variables that are: economy (E), local tourism (T), protection effort (P), and recreation (R).

multicriteria analysis to decide about the final destination for each wetland.

Multiple-Criteria Analysis

Multiple-criteria analysis (Voogd 1983) allows one to compare alternatives on the basis of a set of criteria. They are measurable aspects by which the dimensions of the various choice possibilities under consideration can be characterized. Calculation was performed by means of DEFINITE, a decision support software package developed by Janssen and van Herwijnen (1994). To produce robust results four methods were used: weighted summation, expected value, regime, and evamix. Details concerning algorithms and standardization procedures are in Voogd (1983) and Janssen and van Herwijnen (1994).

Multiple-criteria analysis requires that a value of importance or priority be assigned to each criterion. Quantitative weights are assigned on the basis of qualitative statements that reflect relative importance of criteria. All possible pairs of criteria are compared using the following nine-point scale (Saaty 1980):

1. equally important
3. moderately more important
5. strongly more important
7. very strongly more important
9. extremely more important

For any pair of criteria, say *i* and *j*, the above scale yields a coefficient a_{ij}. All the coefficients form the so-called pairwise comparison matrix A (Janssen and van Herwijnen, 1994). The Eigenvector of A with the highest Eigenvalue gives the weight vector. In both the frameworks in which MCA is performed in this work the matrix A is the outcome of a priority scale based on experts' opinions and information found in the documentation provided by local authorities.

Stability Analysis

Economic self-sufficiency, which depends on the availability of economic resource, makes the plan feasible in the long run, but its effectiveness also depends on the ability of the system to overcome various other disturbances (economic, social, ecological). Stability analysis can help identify critical aspects in this respect, and it is usually performed by mathematical models.

A system is thought to be mathematically tractable if variables and their interactions can be defined precisely in mathematical terms. Unfortunately, this is not possible in the case discussed here because some of the variables forming the model are rather unusual in the sense that they do not belong to the classical domain of stability analysis (pure economic or ecological variables), and relationships are difficult to translate into mathematical terms. At this stage of investigation the system remains partially specified, and the only possibility to highlight stability properties is through qualitative techniques. Loop analysis is the one used in this study (Puccia and Levins 1985). The model proposed is not for precise quantitative predictions; its main goal is understanding, and, as such, its contribution to the planning phase consists in identifying factors that could play a significant role in the context of system stability and their implications for management.

First key variables are identified: local economy (E), that is, the available stock of financial resources; local tourism (T), as total number of visitors; protection effort (P), as funds for maintaining and ameliorating natural reserves; recreation (R), as resources used to improve the environmental quality of the recreation areas, to promote various types of activity, and to create infrastructures. Also for both natural reserves and recreation sites R and P include an amount of resource necessary to maintain efficient connectivity between the channel and the wetland as the future of the sites strongly depends on it.

The variables are represented in a graphical form as large labeled circles. Both R and P consume resource E, while R has a positive effect on the number of visitors (T). This, in turn, is beneficial for local economy (E). These relations can be depicted by connecting lines of two types: arrows for positive relations, and circle head links for negative ones. The resulting model is given in Figure 2.

There are other links whose meaning is not of immediate or intuitive comprehension. A self-link, a link connecting one variable with itself, characterizes all

Table 1. Effect table for the protection plan (negative values score cost criteria)

Criterion	Wetland 1	2	3	4	5	6	7	8	9	10	11
Distance (ord.)	3	1	1	3	1	2	1	3	3	1	3
Border (%)	84.25	90.58	59.05	56.37	70.53	80.39	70.84	73.22	76.45	83.9	83.9
Buffer ($m^2 \times 10^4$)	−30.20	−129.7	−56	−51.5	−33.5	−93.3	−39	−302	−516	−39	−341
Plants (no.)	16	37	34	34	35	14	21	62	3	20	39
Animals (no.)	32	87	23	43	45	33	50	28	33	7	5
Rare plants (no.)	1	3	5	4	1	1	4	5	3	6	6
Rare animals (no.)	4	22	5	14	9	10	9	0	33	2	0
Oxygen (mg/l)	11.9	13.9	10.5	4	4.80	10.10	1.20	9.20	10.9	8.60	9.30
Chlor *a* (µg/l)	−379.58	−78.01	−134.82	−14.72	−46.15	−21.01	−79.87	−141.92	−18.3	−36.23	−72.67
Disturbance (no.)	−2	−1	−1	−2	−2	−1	−2	−2	−2	−1	−1

the nodes but R. Variable E needs a self-damping, that is, a negative self-link because there is a continuous supply of money due to royalty rent (see Puccia and Levins 1985, for a detailed discussion about self-damping). The self-loop on P considers the reluctancy of local administrations to increase expenditure for natural reserves, especially if resources are used to convert more arable land and to increase surveillance, two measures that local communities may not like and that can cause conflicts. There is no reason to consider the two self-effects of the same magnitude. One ($-a_{EE}$) depends on the input of money due to royalty rent and as such can be quantified; the other ($-a_{PP}$) depicts an attitude shown by administrators forced by the public opinion, and it is very hard to quantify although its effect on the whole system is very real.

R is not limited by its growth. In the context of nonconsumptive wildlife-oriented recreation, as the system proceeds toward more mature stages resource requirement may increase as well (Duffus and Dearden 1990). In fact, whereas at earlier stages resources are needed to create infrastructures, later on they are used up to improve services and facilities. The number of visitors (T) is self-damped because crowding discourages more tourists to visit the sites.

Testing this model for stability may reveal critical aspects for the optimal performance of the management plan. The reader can refer to Puccia and Levins (1985) for a detailed explanation of the algorithm used, but suffice to say that stability analysis considers circuits formed by links and their associated feedbacks. A circuit is a series of links that starts at one node and returns to it without crossing intermediate variables more than once. Circuits can be identified on the graph by following the direction of links. They constitute different levels of feedback depending on the number of variables they connect. For example all the self-damping terms belong to the first level of feedback as each of them involves only one variable. There are as many levels of feedbacks as variables in the system. In the graph of Figure 2 there are four levels of feedback: F_1, F_2, F_3, F_4. Circuits linking a certain number of variables can be combined to form an upper-level feedback (i.e., the three self-damping can be combined to form a circuit in F_3). They are called conjunct loops.

Associated with any circuit there is a feedback. It can be positive or negative, and its sign is obtained by multiplying the sign of the coefficients a_{ij} attached to the links. The result must be further multiplied by $(-1)^{m+1}$ where m is the number of disjunct loops that enter in the circuit. The first condition for stability is that all the levels of feedback must be negative ($F_k < 0$, $k = 1, 2, 3, 4$). Yet negative feedbacks produced by longer loops must not be too strong when compared to those from shorter ones (second condition for stability). For a four-variable model this corresponds to $F_1F_2 + F_3 > 0$.

Results and Discussion

Create an Effect Table for the Protection Plan

The multiple-criteria analysis prescribes that real or potential impact of the alternatives on relevant aspects of the real world, that is the criteria, are expressed as scores in an effect table. The effect table for the protection plan is given in Table 1. Criteria have been selected considering three angles of incidence: design, environmental quality, and wildlife. Design includes aspects related to morphological characteristics that render a certain site suitable to host a reserve. These are (1) the distance from the closest human settlement; (2) the degree of isolation that border morphology guarantees to the site; and (3) the amount of land that must be converted into a buffer zone for protection.

In multiple-criteria analysis, certain criteria reflect an advantage with respect to the objectives of the analysis. That is the higher they score in the effects table, the better it is. They are called benefit criteria. Distance belongs to this category, as the farther the site from human settlements the more protected it is. People's tendency to visit a site decreases with increased distance. In particular it has been observed that if the site remains within 1 km from the closest human settlement the probability to be visited is fairly high. After 1 km the likelihood sharply decreases and remains almost the same as the distance increases further. Scores, using an ordinal scale, are assigned accordingly. For sites more than 1 km from the closest village the score is equal to 1. For those located between 0 and 1 km the score is 2, and wetlands near a village have received a score equal to 3. The ordinal scale imposes to assign scores equal to the positions occupied in the ranking.

Cost criteria are those for which the lower score is better. To create a buffer zone, a certain amount of land has to be converted from agriculture. Farmers must be convinced to sell it and be paid for it. This becomes more difficult and expensive as the surface required increases. Land to be converted is a quantitative cost criterion and scores in the effects table are in m^2. The criterion dealing with the degree of isolation is abbreviated as border effect. Scores are defined according to the observation that when a sharp discontinuity exists between the area designed to host a reserve and its surroundings it is due to one (or more) of the following features: the main river, a side channel or stream tributary of the main river, a dike, or a road. Each of these offers a certain degree of isolation that is maximum for the main river and progressively decreases when there is a channel, a dike, or a road.

To assign the scores the amount of border made by each of these objects has been calculated. Next, each length has been multiplied by a coefficient of protection that ranges from 0 to 1. The main river receives a value of 1 as practically no interference can come through it and the entire segment effectively protects the wetland. As the other features offer less protection their coefficients are: 0.75 for side channels and stream tributaries, 0.5 for dikes, and 0 for roads as they do not deter humans at all. The scores in the effect table are given as percentage of border that offers protection.

Environmental quality is made up of water quality and anthropogenic disturbance. The latter refers to the different forms of disturbance that have been identified during the survey and that include hunting (it affects the stopover and wintering of migrant waterfowl), disposal of solid wastes, presence of exotic species (mainly fish), and risk of siltation. It is a cost criterion, and for each wetland the score is simply the number of types of disturbance, among those listed above, that have been observed in the site. Major water quality problems are due to high primary production and anoxic conditions (Viaroli and others 1996). Chlorophyll *a* and oxygen concentration seem appropriate indicators, and they enter as criteria in the effects table. Oxygen is a benefit criterion, since high concentration indicates better conditions for aquatic life, while chlorophyll *a* is a cost criterion because an excess of primary production creates altered conditions due to accumulation of organic matter.

Scores for the two criteria are mean values calculated from data collected during a sampling campaign that was conducted monthly in summer 1996. Due to the limited extension of the water bodies, only one sampling station was active in each site. The standard error has been utilized to perform sensitivity analysis as it measures the uncertainty about the scores. Sensitivity analysis requires that uncertainty is given as percentage of the actual value in the table, and the value calculated using the standard error for oxygen and chlorophyll *a* has been augmented to a fixed value equal for all the wetlands (30% and 20% for chlorophyll *a* and oxygen, respectively). This introduces a precautionary approach and simplifies the procedure.

Wildlife is the third angle of incidence. Each site was monitored for plant and animal species by different authors and data have been summarized by Ricci (1996). Focus is on native species, both plants and animals, that have become locally rare; their number for each site enters the effect table to score four criteria, all benefit: total number of plant species, total number of animal species, number of rare plants, and number of rare animals.

To calculate weights rare species received the highest priority, followed by a set of four criteria: animal and plant species, oxygen, and chlorophyll *a*. Next, distance and buffer resulted as equally important with respect to one another and more important than disturbance, which in turn was judged more important than border effect. Translated in terms of the nine-point scale these priorities yield that rare plants and rare animals (equally important, 1) are extremely more important than border (9), very strongly more important than disturbance (7), strongly more important than distance and buffer (5), and moderately more important than the remaining four criteria (3).

Complete consistency requires that reciprocal positions are defined according to the above scale. So, for example, animal and plant species, oxygen, and chlorophyll *a* (same importance, 1) are very strongly more important than border (7), strongly more important than disturbance (5), moderately more important than distance and buffer (3), and moderately less important

Table 2. Matrix A used to calculate the vector of weights

	Border	Disturb.	Distance	Buffer	Plants	Animals	Oxygen	Ch *a*	Rare P	Rare A
Border		1/3	1/5	1/5	1/7	1/7	1/7	1/7	1/9	1/9
Disturb.	3		1/3	1/3	1/5	1/5	1/5	1/5	1/7	1/7
Distance	5	3		1	1/3	1/3	1/3	1/3	1/5	1/5
Buffer	5	3	1		1/3	1/3	1/3	1/3	1/5	1/5
Plants	7	5	3	3		1	1	1	1/3	1/3
Animals	7	5	3	3	1		1	1	1/3	1/3
Oxygen	7	5	3	3	1	1		1	1/3	1/3
Ch *a*	7	5	3	3	1	1	1		1/3	1/3
Rare P	9	7	5	5	3	3	3	3		1
Rare A	9	7	5	5	3	3	3	3	1	

Table 3. Vector of weights assigned to criteria in the protection plan. This weight vector is the Eigenvector of A with the largest eigenvalue

	Rare P	Rare A	Oxygen	Ch *a*	Plant	Animals	Buffer	Distance	Disturb.	Border
Weight	0.234	0.234	0.101	0.101	0.101	0.101	0.045	0.045	0.024	0.014

than rare species (1/3). The complete set of priorities for the selected criteria, that is matrix A, is reported in Table 2, in which each coefficient gives the dominance of the row criteria over the column criteria. Table 3 reports the vector of quantitative weights obtained from matrix A.

Create an Effect Table for the Recreation Plan

Recreation areas must be designed in accordance with the principles of nonconsumptive wildlife-oriented recreation, and preference must be given to activities such as bird-watching, biking, canoeing, photographic trips, and nature walks. Viewed in the perspective of their users, sites for recreation present a sequential change in the type of visitors that begins with a stage dominated by exploratory users, the so-called wildlife specialists. As the awareness of the site and associated activity grows, less ambitious users will dominate. This more mature stage is the one that likely provides economic return, but it is only the final step in the process of colonization by tourists (Duffus and Dearden 1990). The initial phase is crucial for the entire evolution of the area; in this light rare animal, rare plants, and number of bird species play a decisive role and deserve to be included among the criteria for comparison.

Design as angle of incidence must be included as well. Among the relevant criteria are the dimension of the site in m^2 (benefit criterion) and the amount of land that is needed for reshaping purposes and building infrastructures. As in the protection plan, it has to be converted from intensive agriculture and scores are given in m^2. Distance is included as well, and it is still expressed on a ordinal scale. In comparison with the previous case, however, sites are divided in two categories: those located within 1 km from the nearest village, which receive a score equal to 1, and areas farther than 1 km (score = 2).

Considering environmental quality disturbance (hunting, waste disposal, siltation risk, exotic species), a cost criterion, still remains a crucial aspect. Sites with a low degree of disturbance (in terms of presence/absence of the four types of impact) are the more suitable to host recreation areas. As in the protection plan, indicators of water quality are oxygen concentration and chlorophyll *a* content. Here oxygen becomes a cost criterion, while chlorophyll *a* changes to a benefit criterion. As interventions to prepare the site may improve water quality by restoring earlier hydraulic conditions, it seems convenient that such interventions take place in sites characterized by bad water conditions.

To summarize, the 11 perifluvial wetlands have been compared for their performance with respect to the following criteria: (1) distance; (2) extension; (3) rare plants; (4) rare animals; (5) bird species; (6) buffer zone; (7) oxygen; (8) chlorophyll *a*; (9) disturbance. Table 4 shows the effects table for the recreation plan. Qualitative statements about the relative importance of criteria have yielded the following rank:

1. birds, rare plants, rare animals;
2. dimension, distance;
3. disturbance, oxygen, chlorophyll *a*;
4. buffer.

Table 4. Effect table for the recreation plan

	Wetland										
Criterion	1	2	3	4	5	6	7	8	9	10	11
Distance (ord.)	1	2	2	1	2	1	2	1	1	2	1
Buffer ($m^2 \times 10^4$)	24	110	49	41	300	75	29	260	41	26	300
Birds (no.)	29	73	17	26	39	33	31	19	27	7	5
Rare plants (no.)	1	3	5	4	1	1	4	5	3	6	6
Rare animals (no.)	4	22	5	14	9	10	9	0	33	2	0
Oxygen (mg/l)	−11.9	−13.9	−10.5	−4	−4.80	−10.10	−1.20	−9.20	−10.9	−8.60	−9.30
Chlor *a* (µg/l)	379.58	78.01	134.82	14.72	46.15	21.01	79.87	141.92	18.3	36.23	72.67
Dimen. ($m^2 \times 10^4$)	60.4	162.2	74.4	103	372.2	186.6	97.4	378.6	103.3	130	455
Disturbance (no.)	−2	−1	−2	−2	−2	−1	−2	−2	−2	−1	−1

Table 5. Weights assigned to criteria in the Recreation Plan

	Rare P	Rare A	Birds	Dimens.	Distance	Disturb.	Oxygen	Chl *a*	Buffer
Weight	0.226	0.226	0.226	0.108	0.108	0.030	0.030	0.030	0.016

Table 6. Rankings obtained for the protection plan using four multiple-criteria analysis methods

Wetland	Weighted summation	Regime method	Expected value	Evamix
Lanca Boscone Cusani (1)	11	10	11	11
Lanca Bosco Pontone (2)	1	1	1	1
Acquitrino Mezzanone (3)	3	4	4	4
Invasi Ca' Fittabile (4)	5	2	5	5
Lanca Ca' Bonissima (5)	10	8	10	10
Lanca Argine Babina (6)	9	7	9	9
Lanca Po (7)	8	4	8	8
Ongina Vecchia (8)	7	9	7	7
Lanca di Zibello (9)	4	6	2	2
Lanca di Stagno (10)	2	5	3	3
Lanca di Torricella (11)	6	11	6	6

These priorities are based on a series of considerations. When a recreation area is established it should be attractive for wildlife viewing. This, combined with the need of preserving rare species, justifies the highest priorities given to criteria that consider wildlife. As the awareness of the site increases, less ambitious tourists become the dominant group, and they are attracted by sites of large dimensions close to the places where people live.

The creation of buffer zone may open up opportunities for agriculturists to introduce low-input agriculture, compatible with environmental quality and human presence and farmers seem less reluctant to give up land for this project; it seems reasonable that this criterion receives the lowest priority, while water quality occupies an intermediate position. The same procedure used to create weights in the protection plan is applied here and the matrix A (not shown) yields the weight vector of Table 5.

The results of multiple-criteria analysis is summarized in Table 6 (protection) and Table 7 (recreation). Each entry of the table denotes the position occupied in the ranking by the row wetland when the column method is applied. Table 8 provides the final ranking for the two management plans. It is obtained by comparison of all the alternatives pair by pair. Consider two choice possibilities, say k and j; if more than 70% of the methods applied rank k over j, then k becomes the most preferred alternative (Janssen and van Herwijnen 1994). Sensitivity analysis performed with respect to oxygen and chlorophyll *a* scores did not change the rankings.

Destination of the Areas

Decision making concerning the fate of each wetland is based on the following procedure. The position that the wetland occupies in the two rankings is considered with the highest priority. If a certain wetland ranks almost the same in the two frameworks, then a clear

Table 7. Rankings obtained for the recreation plan using four multiple-criteria analysis methods

Wetland	Weighted summation	Regime method	Expected value	Evamix
Lanca Boscone Cusani (1)	11	8	11	11
Lanca Bosco Pontone (2)	1	1	1	1
Acquitrino Mezzanone (3)	9	7	8	8
Invasi Ca' Fittabile (4)	3	2	3	3
Lanca Ca' Bonissima (5)	10	5	10	9
Lanca Argine Babina (6)	6	6	9	10
Lanca Po (7)	7	3	6	6
Ongina Vecchia (8)	5	9	5	5
Lanca di Zibello (9)	2	4	2	2
Lanca di Stagno (10)	8	10	7	7
Lanca di Torricella (11)	3	11	4	4

Table 8. Final rankings and net value for each wetland

Wetland	Net value (millions)	Protection	Ranking	Recreation
Lanca Bosone Cusani (1)	−323	2	First	2
Lanca Bosco Pontone (2)	−543	10	Second	9
Acquitrino Mezzanone (3)	+200	9	Third	4
Lanca Argine Babina (6)	+640	3	Fourh	11
Lanca Po (7)	−303	4	Fifth	8
Ongina Vecchia (8)	−633	11	Sixth	7
Lanca di Zibello (9)	−343	8	Seventh	10
Lanca di Stagno (10)	+130	7	Eighth	3
Lanca di Torricella (11)	+170	6	Ninth	6
		5	Tenth	5
		1	Eleventh	1

decision cannot be made and the net value under the hypothesis that the area is dedicated to recreation enters in the evaluation; the final decision about certain sites may be the result of an overall economic balance.

Results show that extraction is an appropriate use for wetland 5; its position in both rankings is very low. Wetland 4, on the contrary, is compatible with recreation, and this introduces some uncertainty about its optimal use. As these are the only sites in which dredging is possible, it seems reasonable that their destination remains unchanged. Also it must be considered that after 5 years of exploitation these sites will be restored at the expenses of sand companies, with new opportunities for other uses in the long term.

Table 8 tells one that wetland 1 shows scarce suitability for both management hypotheses. Going through the effects tables (Table 1 and Table 4), one realizes that this site does not have bad scores for most of the criteria. However, it scores badly for those criteria with higher priority in the weighing systems, such as chlorophyll concentration, number of rare species, and number of plant species. A decision about this wetland is postponed until clear indications about possible destination of the other sites will emerge from the discussion.

Wetland 2 is the best in both rankings, but its net value is negative (see Table 8) because no dredging is planned for reshaping, as water circulation is not compromised and cost for implementing a recreation site cannot be compensated for. A natural reserve in site 2 seems thus the best alternative. Consider wetland 10. It ranks better in the protection framework. Net value is positive and speaks in favor of recreation. However, the site ranks very differently in the two plans (second and tenth place, respectively), and the difference is strongly in favor of a natural reserve.

Wetland 9 ranks very well in both cases (second and third place). The better solution is to use it for a recreation site, although a reserve would be acceptable. Net present value is negative, and since the difference in the rankings is not very high the site could be used as natural reserve.

Wetland 6 occupies the same low position in the two rankings. Its net value is positive, and preference should be given to recreation. Wetland 7 performs better in the recreation plan. Also, oxygen concentration is very low if compared with the European standards (Chiaudani and Premazzi 1992), and this body of water urgently needs interventions to restore acceptable conditions. Although its net value is high and negative, critical

Table 9. Calculation of the Routh-Hurwitz criteria for the model of Figure 2

Routh-Hurwitz criteria for stability
$F_1 = -a_{EE} - a_{PP} - a_{TT} < 0$
$F_2 = -a_{EE}a_{PP} - a_{EE}a_{TT} - a_{PP}a_{TT} - a_{EP}a_{PE} - a_{RE}a_{ER} < 0$
$F_3 = -a_{RE}a_{ER}a_{PP} - a_{EP}a_{PE}a_{TT} - a_{RE}a_{ER}a_{TT} + a_{RE}a_{TR}a_{ET} - a_{EE}a_{PP}a_{TT} = ?$
$F_4 = -a_{RE}a_{ER}a_{TT}a_{PP} + a_{RE}a_{TR}a_{ET}a_{PP} = ?$
$F_1F_2 + F_3 = +a_{EE}^2a_{PP} + a_{EE}^2a_{TT} + 3a_{PP}a_{TT}a_{EE} + a_{EP}a_{PE}a_{EE} + a_{RE}a_{ER}a_{EE} + a_{PP}^2a_{EE} + a_{PP}^2a_{TT} + a_{EP}a_{PE}a_{PP} + a_{RE}a_{ER}a_{PP} + a_{TT}^2a_{EE}$
$+ a_{TT}^2a_{PP} + a_{EP}a_{PE}a_{TT} + a_{RE}a_{ER}a_{TT} - a_{RE}a_{ER}a_{PP} - a_{EP}a_{PE}a_{TT} - a_{RE}a_{ER}a_{TT} + a_{RE}a_{TR}a_{ET}$
$= +a_{EE}^2a_{PP} + a_{EE}^2a_{TT} + 3a_{PP}a_{TT}a_{EE} + a_{EP}a_{PE}a_{EE} + a_{RE}a_{ER}a_{EE} + a_{PP}^2a_{EE} + a_{PP}^2a_{TT} + a_{EP}a_{PE}a_{PP} + a_{TT}^2a_{EE}$
$+ a_{TT}^2a_{PP} + a_{RE}a_{TR}a_{ET} > 0$

environmental conditions suggest to intervene on the site and create an area for tourism.

Destination seems now defined for six wetlands. Natural reserves should be realized in sites 2, 10, and 9, while wetlands 11, 6, and 7 should host recreation programs. The net value of these sites yield an overall positive economic balance of 57 million L. Of the remaining zones, site 8, ranks better in the recreation plan, but with an associated net value of −633 million L. This excess of cost could be compensated for by using wetland 3 for recreation, as site 1 also shows a negative net value. However wetland 3 ranks better in the protection plan.

Different solutions are possible. One that gives priority to the vocation of each site as it emerges from multiple-criteria analysis would include site 8 among those for tourism and wetland 3 among natural reserves, with an overall economic balance for implementation of −126 million L, which further diminishes to −449 million L if wetland 1 becomes a site for recreation. Let us call this solution plan A. Its negative economic balance based on net values requires that part of the budget made available by royalty rent from sites 4 and 5 is allocated to cover this excess of cost, thus reducing the overall amount of money available for the program to 16,230 million L. Considering maintenance costs for the different destinations of the nine wetlands in plan A, the life-span of this plan is of about 28 years, but a precautionary approach should consider a shorter period.

A more economically oriented solution, called plan B, would consider site 3 for recreation. Its positive net value could compensate for implementation costs of a recreation area in site 8. Wetland 1 could be used for protection in order to have more or less the same number of wetlands for recreation and for protection. The overall economic balance would be positive by 74 million L in this plan, and the total amount of money available for the program augments to 16,753 million L (16,679 + 74), sufficient to sustain plan B (in theory) for about 30 years. In a final management plan these calculations will have to be corrected to take into account further expenses for promotional activities, maintenance, and more facilities. Yet aspects such as inflation and cost for labor should be revised year by year.

Other options are possible considering different destination for sites 3, 8, and 1. Any solution, however, seems compatible with the objective of maintaining the program for a period sufficiently long to guarantee that tourism activity takes hold and begins to produce economic return. Only in this case can the goal of economic self-sufficiency be achieved.

Stability Analysis

Results of calculation are summarized in Table 9. In this model, the second condition for stability is met, while the sign remains ambiguous for F_3 and F_4. Consider the latter. The negative term is made of the two-node loop [*E*°–*R*], plus the self-damping on local tourism ($-a_{TT}$) and on protection ($-a_{PP}$). This feedback must counteract the positive term, produced by the three-node loop [*E*–*R*–*T*], plus the self-damping on P. As the two feedbacks share two links, namely the beneficial effect of E on R and the self-damping on P, it follows that the system is stable if $-a_{ER}a_{TT} + a_{TR}a_{ET} < 0$.

The attractiveness of recreation areas combined with economic return due to tourism must be counterbalanced by high consumption of resource by R and limitation on the number of tourists. This condition seems very restrictive as usually maximization of economic benefit is the goal of any management strategy, and in this plan economic return depends on the presence of tourists and attractiveness of the areas. However stability analysis emphasizes consequences in the long term and if maximization of economic return in the short period is pursued, it may lead to compromise of the quality of the sites (because of crowding), which soon will lose their attractiveness, further reducing the number of tourists and economic return. If benefit is to be maintained in the long term, as any sustainable policy should include among its priorities, regulation on the number of visitors must be adopted, if this number tends to increase. This measure would have the effect of augmenting the strength of the self-damping in the model.

Particular attention must be given to the self-loop on E. The continuous supply of money from royalty rent will cease after a certain number of years, with potential consequences on the program. Stability analysis reveals, however, that no consequences are expected if the term $-a_{EE}$ is excluded form the model. In fact it does not enter in the composition of F_4, and the condition for stability remains the same as discussed before.

This term enters in F_3 as a conjunct loop, in combination with the other self-damping coefficients. The associated feedback is negative. Excluding this link from the model thus reduces the strength of the negative part of F_3, but with no consequences on model stability. If the condition for stability is met at F_4 it holds also at F_3. The supply from royalty rent is not necessary to guarantee stability, but this conclusion holds in the context of a feasible system, that is, a system in which local tourism effectively provides economic return. This highlights the importance of royalty rent for the feasibility of the system.

Concluding Remarks

In this paper a strategy for the sustainable use of 11 perifluvial wetlands of the Po River is presented and discussed. It integrates different approaches: simple economic analysis, multiple-criteria techniques, and qualitative modeling. Besides the results concerning the optimal use of each wetland, some general observations can be made.

To decide about the optimal use of a perifluvial wetland is a controversial issue because of different needs and priorities. To reduce conflicts this model proposes a shift in focus: from a site-to-site approach to a global strategy in which the unit of management is a larger area or even a region. This gives the opportunity to conceive management strategies that reconcile ecological integrity, intergenerational opportunities, and economic efficiency, three key dimensions of the sustainable development paradigm (Bender and others 1994).

Conditions for stability in this system reveal that profit in the short term, certainly the prime objective of most enterprises or institutions, is not compatible with the idea of sustainability that emerges from this investigation. Shortsighted pragmatism that still dominates planning and management must be abandoned if sustainability has to become the real objective of any practice.

Although the potential to apply this model in other situations is promising, it has to be intended mostly in terms of encouragement and awareness rather than being prescriptive. The notion of sustainability is less ambiguous then it appears in the literature, but it is certainly dynamic: there are no optimal solutions or final states, just trajectories.

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