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ANALYSIS

An ecological integrity assessment of a Brazilian Atlantic Forest watershed based on surveys of stream health and local farmers' perceptions: implications for management

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Abstract

While ecosystem services provide benefits at various spatial scales, often the decision to conserve an ecosystem lies with the local people. Knowing the perceptions of local landowners of the benefits provided by ecosystem services cannot only help in the design of efficient mechanisms for environmental conservation, but also in achieving the support of these mechanisms by the local stakeholders. In this article we use both standard scientific assessment and the stakeholders' local ecological knowledge in order to acquire information about both the ecological integrity of an Atlantic Forest watershed, and the ecosystem services it provides. In a small-scale case study of the Macabu River watershed in Brazil, we investigated and compared a rapid field assessment of stream ecological integrity with the stakeholders' local environmental perceptions as revealed through interviews. This comparison indicates that the farmers tended to overestimate the ecological integrity of the stream reaches located inside their properties. However, the farmers also showed ecological knowledge about the environment and forests' ecosystem services, such as the maintenance of water supply and suitable climatic conditions. Our results thus indicate that the farmers' perceptions about the environmental impacts and ecological integrity of forest and water are apparently more strongly influenced by direct uses and opportunity costs, representing a market failure of asymmetrical information. Such market failure could be overcome by more fully informing farmers about ecosystem services and possible direct economic advantages of riparian forests.

Keywords: Local ecological knowledge; Forest management; Watershed; Stream quality; Biological conservation

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1. Introduction

Local human populations that directly depend upon natural resources usually have ecological knowledge about these resources (Gadgil et al., 1993; Williams and Baines, 1993; Berkes, 1999). Such local knowledge, usually acquired through experience and oral transmission, often accounts for the inter-relationships among animals, plants, humans and the environment, resembling in some aspects ecological concepts held by scientists (Berkes et al., 1998). Thus, local ecological knowledge is an important keystone to the design and structure of natural resource management strategies. Additionally, while local knowledge often provides guidelines and new information for biological research (Ruddle, 2001), the combination of local ecological knowledge of resource users and scientific information has proven useful to the management of forests and watersheds (Jesus et al., 1995; Johns, 1999; Hildén, 2000; Robertson et al., 2000; Quansah et al., 2001).

Tropical forests are the richest terrestrial ecosystems in terms of biodiversity and structural complexity. These forests play important ecological functions, such as climatic regulation (heat absorption, humidity regulation), water and nutrient cycling, maintenance of biodiversity and reduction in the emission of greenhouse gases (e.g., CO_2), among others (Whitmore, 1990). Such ecological functions provide valuable ecosystem services to human populations, such as climate stability, water provision, pollination of crops and pest control (Costanza et al., 1997; Fearnside, 1997; Brown, 2001; Pearce, 2001). Land use practices that reduce riparian forest cover have several impacts upon streams, such as the increase in sediment load and nutrient enrichment due to runoff, as these forests are essential to the maintenance of the ecological integrity of rivers and their associated watersheds (Calow and Petts, 1994; Ataroff and Rada, 2000; Neill et al., 2001).

The two principles of sustainable development for the management of renewable resources are that harvest rates should not exceed regeneration rates and waste emission rates should not exceed natural assimilative capacities of the ecosystems, as these regenerative and assimilative properties should be regarded as natural capital (Daly, 1990). The management of natural resources is usually trusted to market forces, but ecosystem services lack the characteristics necessary for efficient market allocation, as they are non-excludable, non-rival, and damaged by negative externalities. In addition, most of the benefits of ecosystem conversion are readily quantified, while both the services provided by intact ecosystems and the impacts of conversion on these services are, for the most part, only poorly understood—a variation on the market failure of asymmetric information. This often leads to inefficient management and as a consequence tropical forests are being cleared at an accelerating pace, primarily to supply the demands of market and subsistence goods for an ever-increasing human population in tropical developing countries (Whitmore, 1990). Fragmentation is one of the most prejudicial impacts suffered by tropical forests, being responsible for species extinctions, alterations in the composition of plant and animal communities, and changes in ecological processes (Harris and Silva-Lopez, 1992). Conversion of land into pasture, frequently subsidized by government incentives, has been one of the leading forces of forest destruction and fragmentation in tropical countries, such as Brazil (Nepstad et al., 1991; Moran, 1993).

Severely threatened by deforestation and boasting some of the highest recorded levels of terrestrial biodiversity and species endemism, the Brazilian Atlantic Forest is considered a global biodiversity hotspot. This forest ecosystem has been largely cleared as a result of centuries of human exploitation. Containing within its former boundaries the majority of the Brazilian population and two major urban centers, São Paulo and Rio de Janeiro, today only approximately 7% of its original vegetation cover remains. The economic exploitation and land use of the southeastern Brazilian Atlantic Forest began with logging, followed by coffee and sugarcane plantations and more recently by cattle ranching (Mittermeier et al., 1999). Such destructive economic uses should be urgently changed in order to stop the irreversible loss of Atlantic Forest biodiversity and the important ecosystem services it provides.

Given the current trends of human population growth and increasing demand for natural resources, stakeholders should be identified and involved in the development of ecosystem management (Christensen et al., 1996; Gregory and Wellman, 2001). Land degradation problems in tropical American countries are usually site-specific, and therefore are better addressed through local case studies that consider the farmers' point of view. Indeed, involving farmers in land management decisions is crucial to the success of conservation programs (Lutz et al., 1994). In this paper we present a small-scale case study on how the combination of methods based on social and biological sciences may provide a promising way to involve local people in conservation strategies aimed to alter current economic uses and values of forests and rivers. The main objectives of the study are to assess the ecological status of forest fragments and streams, verify the knowledge of the local stakeholders about their environment (including ecological impacts and water quality issues) and compare the information acquired by the two methods. This approach offers new insights into the land management practices within a Brazilian Atlantic Forest watershed.

2. Case study

The freshwater habitats within Rio de Janeiro State are considered regionally outstanding in biological distinctiveness, and some of these freshwater habitats, particularly in the east and southeast Atlantic Forests, are considered endangered ecosystems. Therefore, these habitats have a high priority for conservation (Olson et al., 1998). Presently, Rio de Janeiro State has approximately 22% forest cover which is composed of small and scattered Atlantic Forest fragments, usually located inside private properties (Ministério do Meio Ambiente, 2000). This situation is typical of the Macabu River watershed (Fig. 1), where farmers' agricultural activities shifted from plantations for coffee in the past to pasture for milk producing cattle. Deforestation along the Macabu River and its tributaries is so pronounced that many streams have almost entirely lost their riparian forest cover (Fig. 2). The municipality encompassing the study site, Conceição de Macabu, has a high density of cattle, and a high rate of herd growth relative to other municipalities in Rio de Janeiro state (Young et al., 2000, unpublished monograph), which together pose serious threats to the remaining forests.

According to the classification of the Brazilian's National Agency for Water (ANA), Macabu River is part of the Macaé River sub-basin of the Brazilian eastern Atlantic Basin, which is included in the southeastern Atlantic hydrographic region. This hydrographic region is facing serious problems of water shortage as it has 214,925 km^2, with a population of about 25.2 million. Considering the importance of riparian buffers, it is not surprising that Rio de Janeiro State has one of the lowest per capita water availability indices in Brazil, with only 2.3 m^3/person/year (Rebouças, 1997). Watershed management in order to mitigate or reverse deforestation would thus be of prime importance in order to sustain water quality and quantity in the whole watershed.

The Macabu River watershed region, albeit not considered itself a priority to conservation, is located between two high priority Atlantic Forest areas, Poço das Antas and Serra dos Órgãos (Ministério do Meio Ambiente, 2000) and may thus be of importance as an ecological corridor linking these two areas. Within the Macabu River watershed, a Brazilian NGO (Pro-Natura) initiated a "Forest Strand" (*Cordão de Mata*) project with the goal of establishing connections between the sparse Atlantic Forest fragments. Most of these fragments are located on hilltops and are private property (Fig. 2). In order to implement this conservation strategy, the NGO has been working with local farmers to find economically feasible ways to change current land use patterns, from pasture to reforestation, especially near the rivers (May, 2002).

The present research was conducted along the Macabuzinho River (from upstream to the river mouth), a tributary of the Macabu River watershed. The Macabuzinho River has an average flow of 12.8 m^3/s and its ecological integrity and water quality are of more immediate concern because the sub-watershed provides drinking water to the largest city in the region, Conceição de Macabu (Fig. 1). Water from the river is insufficient to meet household needs during certain periods of the year, water quality is poor and the town has limited resources to deal with this problem, due to low per capita income (Young et al., 2000, unpublished monograph).

The main goals of our research are to evaluate the ecological integrity of the streams within the Macabuzinho River watershed, and to record the farmer's perceptions on ecological impacts, forest–water rela-

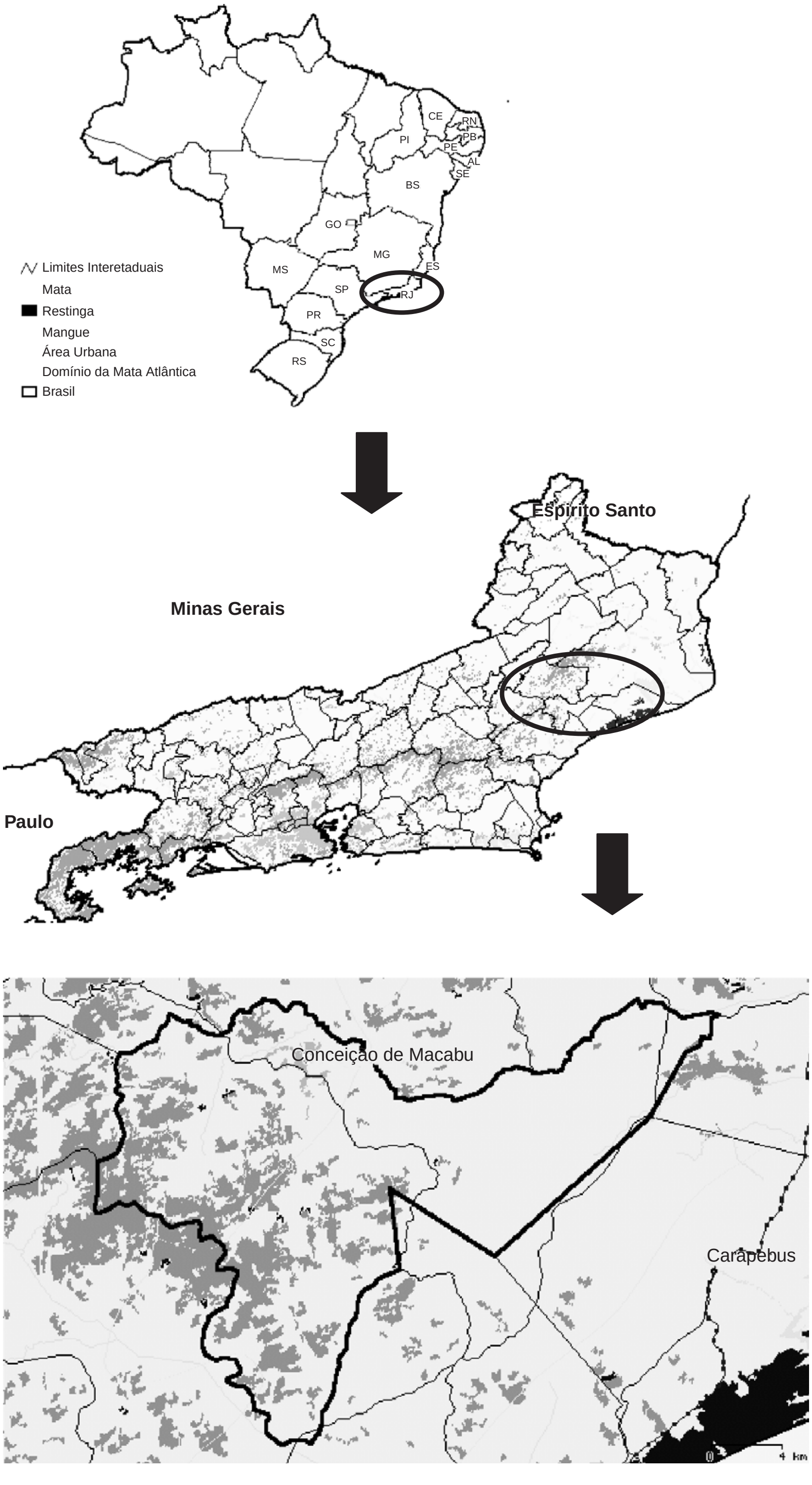

Fig. 1. Location of the study area, the Macabu River watershed, at the southeastern Brazil.

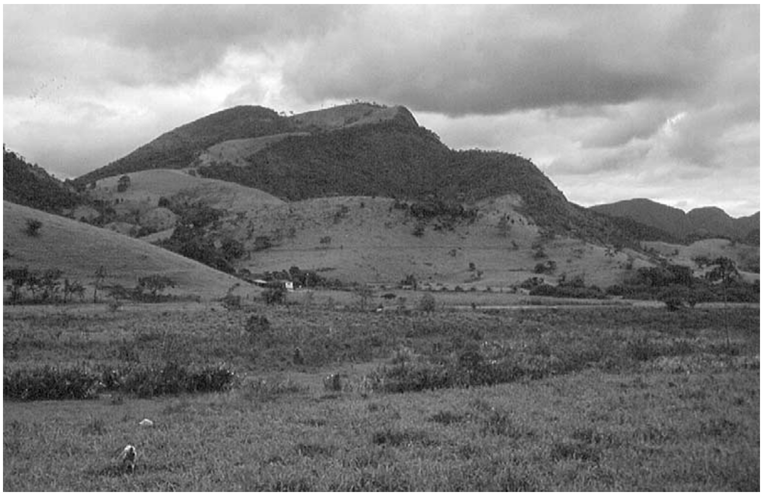

Fig. 2. Typical landscape along the Macabu and Macabuzinho Rivers, consisting mainly of pastures for raising cattle and forest fragments on hilltops.

tionships and water quality issues. In doing so, we intend to address the questions: (1) "How do people think about their watershed?"; (2) "How do people perceive the ecological impacts and degradation of their watershed?" and (3) "To what extent do people's perceptions correlate with the results from the visual stream assessment?" The resulting information would help both to state how conservation/educational strategies need to be tuned to local farmers' knowledge and to explore the feasibility of using economic incentives to preserve the remaining forest fragments. Furthermore, these results could be useful to assist the government, local NGOs and stakeholders in achieving proper ecosystem management and restoration of the Macabu River watershed and are potentially applicable to other tropical forest watersheds subject to intensive cattle ranching activities.

3. Methods

We conducted the present study during the Workshop "Restoration of Brazil's Atlantic Forest as a Watershed Management Tool: a Short Graduate Field-Course in Ecological Economics and Sustainable Development", held by the Institute for Ecological Economics, University of Maryland (presently the Gund Institute for Ecological Economics at the University of Vermont) in collaboration with the Federal Rural University of Rio de Janeiro (UFRRJ), and local government and NGOs (Pro-Natura) in Conceição de Macabu (Brazil) during January 2002.

In order to assess local environmental perceptions, we interviewed farmers using standardized questionnaires dealing with land use patterns, ecosystem services, relationships between forest and water, stream quality, sewage disposal and water quality and quantity (Appendix A). We sampled only those farms that have sections of the Macabuzinho River or its tributary streams within the landowner's property, or alternatively farms located within 50 m of the river's edge. We interviewed only those farmers who have been living in the region for five years or more and who frequent the farm year-round. Thus, we did not include tourists or landowners that live in other cities in our survey. We interviewed one farmer per property, usually the principal landowner. The interviewees were found with the help and advice of staff from a local NGO (Pro-Natura) and municipal government of Conceição de Macabu. We also employed the "snow-ball" method, which consists of each person interviewed suggesting other people to interview, thus increasing the sample universe (Bailey, 1982). Based on an initial list of farmers for the Macabuzinho River watershed, we tried to locate those with properties closest to the Macabuzinho River, and interviewed as many of them as possible.

Given limited time and resources, achieving a large sample size was unrealistic. However, anecdotal information from informed stakeholders can make important contributions to understanding and solving problems in rural development (Chambers, 1983) and ecological economics (Funtowicz and Ravetz, 1993; Farley et al., 2004).

Assessments of stream ecological integrity were conducted using the Stream Visual Assessment Protocol (SVAP) at the same farms where the landowners were interviewed. SVAP was developed in concert by the Natural Resources Conservation Service (NRCS) of the U.S. Department of Agriculture (USDA) and the University of Georgia to be a user-friendly method to assess the health of streams by a landowner and a technician. Although there are many voluntary stream assessment programs in the United States, SVAP was developed to provide landowners with a simple alternative to in-depth and often time consuming sampling protocols. SVAP allows the assessor, along with the landowner, to visually assess multiple physical and biological stream parameters within a relatively short period of time and to determine whether additional studies are needed. According to SVAP, a total of 15 possible assessment elements are given numeric values based on the conditions in the field: (1) channel condition; (2) hydrologic alteration; (3) riparian zone condition; (4) bank stability; (5) water appearance; (6) nutrient enrichment; (7) barriers to fish movement; (8) fish cover in the stream; (9) pools; (10) invertebrate habitat; (11) canopy cover; (12) manure presence; (13) salinity; (14) riffle embedded ness; and (15) macroinvertebrates observed. The SVAP protocol provides narrative descriptions for the conditions ranging from "excellent" to "poor" for each of the assessment elements from which the assessor will assign the lowest numeric value (usually from 1 to 10) to match the indicators present within the reach observed. The overall assessment score is determined by adding up the values for each of the assessment elements, further dividing it by the number of elements assessed. Such overall score can be excellent (>9.0), good (7.5–8.9), fair (6.1–7.4), or poor (<6.0). Thus, the assessment assigns a numeric value to the overall environmental condition of the stream reach, providing a general statement about the stream health (http://www.wcc.nrcs.usda.gov/wqam/wqam-docs.html) (Bjorkland et al., 2001; NWCC Technical Note 99-1, Stream Visual Assessment Protocol, 1998).

Although projects like SVAP and "Adopt-A-Stream" are common in the United States, there generally are few in South America. However, an "Adopt-A-Stream" project was introduced to Costa Rican high school students with preliminary success (Laidlaw, 1996). The relevance of adapting protocols such as SVAP on the local level include: (1) local people learn to recognize threats to stream health and how these threats influence watershed dynamics and stream ecology; (2) promotes community involvement in local conservation issues; and (3) providing an avenue for building leadership skills.

In northern Rio de Janeiro, two researchers applied the SVAP assessment protocol to a section of the Macabuzinho River or tributary located within or bordering interviewees' properties. The overall combined value for all the parameters assessed, divided by the number of parameters utilized, provided a total score for the stream condition in each segment. These values were used to infer the health of the streams, which were classified as poor, average, good or excellent. Of the 15 assessment elements usually measured in SVAP, salinity was not an issue at our study site so it was not assessed, as this element is applicable only if elevated salinity levels are known to be a problem due to anthropogenic sources.

4. Results

At the time of the survey, only nine farmers were available and agreed to take part in the study. This small sample size was mostly due to logistical problems. Most of the farmers divided their time between their farms and their homes in town, complicating the task of finding them during their spare time. There was also a large distance between farms, which were difficult to access due to poorly maintained dirt roads. However, the total amount of land owned by the interviewed farmers is 1572.68 hectares (ha) (per farmer estimates), which corresponds to approximately 24% of the total farmland in the entire Macabuzinho watershed. These individuals can thus be considered key players due to their respective influence on river health and the ecological integrity of the watershed. Furthermore, the manner in

Table 1
General characteristics of the interviewed farmers and their properties, ordered according to interviewees' age

	Interviewee's age (years)	Residence time in the region (years)	Age of farm (years)[a]	Property size (ha)	Number of cattle
	40	40	11	135.5	200
	44	44	44	140.0	250
	49	49	10	62.9	0
	50	50	35	148.0	0
	52	52	20	65.0	0
	70	34	34	101.6	23
	70	70	60	96.8	120
	71	71	30	755.0	600
	76	76	40	67.8	80
Mean	58	54	31.6	174.7	141.4
Total				1572.6	1273

[a] Age of farmer refers to for how long the interviewed farmer had been managing that property.

which these farmers manage their land affects the quality and quantity of water provided to the population of Conceição de Macabu. Despite its size limitation, our sample could thus be regarded as qualitatively sufficient, as it includes the principal resource stakeholders around the Macabuzinho River. Some of these stakeholders are rich cattle ranchers with large properties, enjoying some leadership among members of the farming community. Their actions could thus have a proportionately higher impact upon the forest and water resources of the Macabuzinho River basin.

Survey responses on certain issues exceed the sample size, as each person gave more than one answer to the same question. In surveys like this one, involving questions about forbidden actions such as cutting forests, farmers could potentially offer strategic or stereotyped answers. This may partially account for all farmers saying they like forests, but most farmers also stated that they do not want to allow forest area to increase within their properties, indicating that their answers could be honest in a general sense. Furthermore, most admitted to retaining less than the minimum legal forest cover. All nine interviewed farmers use their land to grow pasture, eight of those in order to raise dairy cattle. Most of the farmers mentioned the cultivation of crops, such as sugarcane and corn, used to feed the cattle by respectively seven and five interviewees. Four farmers had fishponds and five had some other kind of crop for human consumption. When asked about the past land use practices in their present properties, five farmers mentioned that their farmlands were already used as pasture before they started to manage their lands, three farmers used their lands to harvest food crops and two farmers cultivated sugarcane.

According to farmers, the size of the sampled properties varied from 63 to 755 ha, with a mean of 175 ha, while the number of cattle raised on each property ranged from 23 to 600, with a mean of 212 cows (Table 1). Farmers mentioned that they use water as drinking water for the cattle, as well as for domestic tasks and for washing the corrals (Table 2). The main water source for household consumption and drinking water was groundwater provided by springs located inside the farmers' properties. Although all the farms had access to the Macabuzinho River or its associated streams, less than a half of the farmers mentioned the river as a water source (Table 2). The septic tank was the main method of domestic sewage disposal, while cattle manure was discharged mainly in the pasture. Only a few of the interviewees disposed of domestic or cattle waste directly to the river (Table 2). All the farmers mentioned that they drink the water (groundwater, Table 2) from their properties and that the water they

Table 2
The sources and uses of water according to interviewed farmers

	Number of interviewees
Water sources	
Spring (ground water)	9
Small reservoirs (rain water)	4
River or stream inside the property	4
Water uses	
Drinking water	9
Domestic	7
Cattle drinking water	7
Washing the corral	5
Irrigation	2
Fishponds	1
Sewage disposal	
Domestic waste in septic tank	6
Domestic waste in the river	2
Cattle dung in the pasture	4
Cattle dung in the river	2
Cattle dung in the septic tank	1
Cattle dung in the sugarcane plantation	1

have is sufficient for their current uses. Similarly, the majority of farmers did not notice any changes in water quality (smell or color) and they think there are still fish in their rivers. However, most farmers noticed changes in the flood regime and a reduction in water quantity, compared to the previous decades (Table 3).

Eleven SVAP assessments were conducted at different farm sites (in two farms we conducted the SVAP survey but could not interview the landowners). Only the assessment elements applicable to the stream reach were analyzed. Of the 14 possible assessment elements, eleven were analyzed at eight sites, nine at one site and ten at two sites (Table 4). The most significant assessment elements (those with the lowest average scores) include canopy cover (4.09), riparian zone (4.55), and presence of dung (4.56) (Table 4). The optimistic view of the farmers about their streams was not confirmed by the results of the stream field surveys made at their properties. According to SVAP, more than half of the stream reaches were considered of poor condition (<6.0), while only one was considered average or fair (6.1–7.4), and two were considered respectively good (7.5–8.9) and excellent (>9.0) (Table 5). Curiously, only one farmer noticed changes in water's color and smell (Table 3), but the stream in his property was considered as of excellent quality (Table 5). Also, considering the two farmers that said there were no fishes in their rivers (Table 3), one of them had good stream in his property (Table 5). These results further suggest that farmers may be failing to properly evaluate the streams' environmental health. When considering the SVAP values along an elevation gradient, the sites at the higher elevations were in better condition (Table 5). This may be due to the fact that the stream impacts are mostly caused by deforestation for pasture to graze cattle and higher elevation sites are less accessible.

Table 3
The farmers' answers to questions about the ecological integrity and environmental change associated with forest and water quality[a]

	Yes	No	Don't know
Water quality questions			
Do you drink the water?[a]	9		
Did you notice changes in the water color or smell?	1	7	1
Did the flood regime change?	6	3	
Do you think that the water quantity is adequate?	9		
Did you notice changes in the water quantity?	8	1	
Are there fish in the river?	7	2	
Forests questions			
Do you have forest inside your property?	9		
Do you believe that clearing all the forest from your property would be a bad thing?	9		
Would you like to have more forest inside your property?	4	5	
Did you ever cut the forest?	2	7	
Had the forest ever been cut in the past?	7	2	
Is the forest important to water provision?	9		
Does the forest influence climate?	9		
Does the forest have any relationship with agro-pastoral production?	6	3	
Would you accept an annuity of R$ 50.00 (about US$ 16.6)[b], to regenerate forest on 1 ha of land each year?[c]	2	7	
Have fires occurred inside your property?	5	3	

[a] The question referred to any kind of water inside the interviewee's property. As explained in text, drinking water here mentioned by farmers is not river, but spring water.

[b] According to exchange rates on June 2004.

[c] This proposed monetary amount is based on a pilot economic survey from the NGO Pro-Natura, considering feasible monetary compensations to farmers.

All farmers mentioned that they have forest patches inside their properties and they do not want to clear all the forest on their land. They also acknowledged that the forest influences local climatic conditions, water provision and agro-pastoral production. However, more than half of the interviewed farmers do not want to have more forest inside their properties and most of them mentioned that forests were cut in the past (Table 3).

The synthesis of all information derived from the questions dealing with forest services, with regard to the influence of forest presence on production, showed that farmers recognized at least 11 forest attributes that affect their land beneficially. The most cited of these forest services were cooling of the environment (microclimate), enhancement of water quality and availability (through water conservation and provision), protection against the wind

Table 4
Average scores for each stream visual assessment element and the number of sites these elements were assessed

Assessment element	Range of score values	Standards for excellent conditions (highest values)	Number of sites[a]	Average score
Canopy cover	1–10	Natural vegetation two times the width of reach on each side of stream.	11	4.09
Riparian zone	1–10	More than 75% of water surface shaded and upstream (two to three miles) generally well shaded.	11	4.55
Manure presence	1–5	No evidence of livestock presence.	9	4.56
Fish cover	1–10	More than seven cover types available: logs/large woody debris; deep pools; overhanging vegetation; boulders/cobble; riffles; undercut banks; thick root mats; dense macrophyte beds; isolated pools; other.	10	5.60
Pools	1–10	Deep and shallow pools are abundant.	10	5.73
Embedded ness	1–10	In riffle, the gravel or cobble substrate is less than 20% embedded (depth to which substrate is buried by sediment).	11	6.00
Macroinvertebrates observed	−3–15	The aquatic insect community dominated by intolerant species with good species diversity. For example, caddisflies, mayflies, stoneflies, and hellgramites.	11	6.36
Insect habitat	1–10	At least 5 types of habitat available: fine woody debris; submerged logs; leaf packs; cobble; boulders; gravel; other.	11	6.45
Nutrient enrichment	1–10	Clear water along entire reach (algal blooms give a greenish color to water); diverse aquatic plant community with low quantities of macrophytes and little algal growth present.	11	6.77
Bank stability	1–10	Level of erosion: many vegetated stretches; few exposed tree roots or 'scalloped' edges; no animal or vehicle paths to water's edge.	11	7.14
Water aspect	1–10	Very clear, or clear but tea colored; no oil sheen on surface; no observable film on submerged rocks.	11	7.82
Channel condition	1–10	In riffle, the gravel or cobble substrate is less than 20% embedded (depth to which substrate is buried by sediment).	11	8.45
Barriers to fish movement	1–10	No barriers	11	9.30
Hydrologic alteration	1–10	Normal flooding, no dams, no water withdrawals, no dikes or other structures, no channel incision	11	9.36

[a] Number of sites where each of these elements were assessed differ because some of these elements were scored only if applicable to our study site.

Canopy cover is thus not measured if the river is larger than 50 feet in length (larger rivers have minimal cover from riparian trees) or if it is woody vegetation is naturally absent as is seen with wet meadows. Manure presence is assigned a score only if livestock or human waste operations are present in the study site. Riffle embedded ness would not be assessed if they naturally do not occur in the river type observed.

Table 5
SVAP values and scores for the eleven sites along an elevational gradient

Site	Elevation (m)	Value	Total score
1	30	Poor	5.29
2	53	Poor	5.54
3	69	Poor	4.50
4	69	Average	6.57
5	71	Poor	5.64
6	76	Poor	4.69
7	80	Poor	5.77
8	80	Good	8.36
9	94	Excellent	9.23
10	101	Excellent	9.54
11	113	Good	8.42

Table 6
Forest services perceived by the interviewed farmers

Forest services	Number of interviewees
Reduction of soil and ambient temperatures	9
Promotes water conservation and regeneration	9
Shade for the cattle	5
Organic matter to the soil	5
Wind protection	4
Humidity maintenance	3
Avian habitat and shelter	2
Filters the water (enhance water quality)	1
Reduces erosion, protects the soil	1
Scenic beauty	2
Provides oxygen	2

(avoiding damage to houses and buildings) and enrichment of soil organic matter (Table 6). Despite their recognition of the role of the forest in providing these important services, most farmers rejected the prospect of receiving payments to regenerate (even through natural succession) native forest on their land (Table 3).

5. Discussion

5.1. Farmer's local ecological knowledge, ecosystem services and SVAP assessments

We considered local ecological knowledge in a broad sense, as any kind of relationship between forests and environmental or biological processes that were mentioned by farmers. Such local knowledge could be perhaps even more detailed than shown here, but to reveal this would require a more in depth ethnobiological survey. For our purposes, it is sufficient to know that farmers from the Macabuzinho watershed have some knowledge about their local environment, as they recognize, in their own terms, some of the benefits provided by the forest inside their properties, such as climatic regulation (reducing soil and environmental temperatures), maintenance of water quality and quantity, provision of shadow for the cattle, barrier for the wind and shelter for birds, which could improve pest control. All these benefits correspond to the scientific concept of ecosystem services (Costanza et al., 1997). Although most of these ecological services still remain to be empirically investigated in southeastern Brazilian Atlantic Forest, farmers' local ecological knowledge is corroborated by available scientific data for tropical forests, according to which forests aid in the maintenance of suitable climatic conditions (Whitmore, 1990; Brown, 2001; Noss, 2001) and the replacement of forests by pasture can reduce water availability (Nepstad et al., 1992; Ataroff and Rada, 2000) and alter soil properties (Reiners et al., 1994). Forests may also reduce pest damage to crops, acting both as a physical barrier and as a source of pests' natural enemies. Woody borders formed by dense and tall vegetation may potentially reduce the movements of pests to crop fields (Bhar and Fahrig, 1998) and specialized insectivorous birds are usually more abundant in forest habitat compared to sites with degraded vegetation (Regalado and Silva, 1997).

Other surveys have also observed that farmers are aware of local ecological processes, such as the relationship of tree shade with microclimate stability and soil fertility (Johns, 1999), the importance of the soil organic matter for both water conservation and as a primary source of nutrients for plants (Quansah et al., 2001), carbon uptake by plants (Lewan and Söderqvist, 2002) or soil characteristics and classification (Oberthur et al., 2004). However, as detailed as it may be, farmers' local knowledge differs from scientific knowledge and the former is not a substitute, but rather a complement, to the second. As an example, interviewed farmers failed to recognize some ecosystem services valued by scientists, such as biodiversity conservation (Fearnside, 1997; Noss, 2001; Pearce, 2001). In such a context, ecosystem management measures may be improved if they integrate locally based information provided by farmers with global and empirical perspectives provided by scientific data (Burgess et al., 2000; Klooster, 2002; Oberthur et al., 2004). The farmers' knowledge about ecological services on Macabu River watershed could be a starting point to enhance dialogue between farmers, scientists and managers, who could provide farmers with information about the natural capital represented by forests inside their properties and possible ways in which this capital could directly benefit them.

According to the SVAP survey, half the stream reaches studied in the Macabuzinho watershed have poor quality, which may be related to the intense clearance of lowland riparian forests, the domestic sewage disposal into the river and the runoff of cattle dung from pasture to the river. Much of the sedimentation problem in Atlantic Forest streams is due to intensive agricultural practices, extensive cattle farming causing additional negative impacts in the form of river bank' erosion (due to unimpeded cattle access and overgrazing), which causes high loads of sediment and nutrients in the run-off reaching the streams and rivers. The increase in sedimentation and turbidity limits photosynthesis and alters substrate and dissolved oxygen levels in the river (Wood and Armitage, 1997).

The comparison between the interviews and stream assessment results indicates that farmers tended to overestimate the ecological integrity, notably the water quality and quantity, of the stream reaches located inside their properties. Such differences between farmers' perceptions and field observations may be related to the fact that the drinking water comes not from the streams, but from the springs, which are located on the hilltops, within forest remnants (Fig. 2). The river water is thus of minor importance to those farmers in spite of its importance to the urban population downstream. The rivers' poor environmental status has probably been aggravated by this perverse feedback: water from rivers is useless due to the ecological impacts of land use practices; these practices, on the other hand, are intensified around the rivers, which are not used locally as a water source. Furthermore, the farmers also did not properly recognize the urgency of some ecological impacts (changes in water quality), they had some difficulty in acknowledging themselves as part of the environmental problems (usually blaming other farmers) and some farmers mentioned a reduction in water quantity, but seemed not yet to be affected by these water shortages. These misunderstandings about river status are obstacles to farmers' involvement with watershed management and the restoration of riparian vegetation. Local River Basin Committees have been successfully implemented in several Brazilian' watersheds, the strongest of these in the study region being the Paraíba do Sul River Basin Committee. It would thus be desirable to create a Macabu River Basin Committee, which could work together with existing Paraíba do Sul Committee, NGOs (such as Pro-Natura), farmers' associations and other sectors of society and develop environmental awareness programs, coupled with river restoration actions, that are tailored to the farmer's community.

5.2. Ecological economics and conservation of the Atlantic Forest

Achieving a socially desirable level of forest cover in Macabuzinho River watershed confronts the compound market failure of public goods and asymmetric information. When deciding whether to retain pasture or allow reforestation on their land (continued deforestation being illegal), rational farmers in the Macabuzinho watershed will compare the marginal benefits they receive with the marginal costs they must pay. If pasture is returned to forest, farmers pay the opportunity cost of decreased pasture land, while the increase in non-rival, non-excludable ecosystem services benefits the entire downstream urban community. Some of the ecosystem services provided by reforestation will also directly benefit the farmers, but to the extent farmers are misinformed about such benefits, they will ignore them. The net result is fewer reforestations than socially desirable. Research results seemed to capture this dynamic: when discussing local environmental impacts and ecological integrity, Macabuzinho watershed farmers' emphasized opportunity costs and those ecosystem services that would be potentially useful, ignoring those without direct usefulness to them, such as biodiversity maintenance. Most of the remaining forest fragments in the Macabu River watershed are on hilltops, which have low opportunity costs as these areas are typically held as unsuitable for pasture and agriculture. However, the hills also harbor the spring water sources. Recognizing the forest's role in maintaining private water supplies, farmers are more prone to let forest grow around the "useful" springs than around the "useless" river margins. This may partially account for the apparent observed contradiction: farmers recognize the usefulness of forests they already have (on hilltops), but at the same time farmers do not want to have more forests inside their property (on lowlands), because they do not see direct benefits from these forests, as forested land reduces the available area for pasture. It would also explain why farmers apparently did not notice a reduction in drinking water quantity or quality, which would be protected by forests retained around their drinking water sources.

This is symptomatic of the market failure of asymmetrical information, where a landowner may have asymmetrical knowledge of the costs and benefits provided by two mutually exclusive uses of an ecosystem (Chivers and Flores, 2002). The benefits of ecosystem conversion (e.g. timber or farm land) are direct, obvious, and easily quantified. The ecosystem services provided by protected ecosystems however are less obvious. A landowner with an incomplete knowledge of the ecosystem services provided, may therefore give them less weight than the direct market benefits (Godoy et al., 2002; Jim and Xu, 2002). Making landowners aware of the direct personal benefits of ecosystem services would probably lead to a more efficient management of ecosystems (Lewan and Söderqvist, 2002).

However, the presence of public good externalities compounds the problem: even if the landowner were aware of the full value of ecosystem services, he may only account for those that provide direct benefit to him; ignoring those that benefit others and lack a price or market value (Pearce, 2001). To address the problem of public goods, non-market institutions such as the State or NGOs should compensate the farmers for the public goods they provide. Farmers educated about the direct benefits they receive from forest ecosystems would likely demand less compensation for restoring forests, an important factor in a region with low per capita income and a subsequent dearth of government resources for such policies. Unfortunately, there are other issues that complicate solutions to this compound problem. On the Macabu River watershed and in other Brazilian rural regions, at least three factors may be aggravating the asymmetrical information failure. First, there could be a long held cultural tradition among farmers of relying on current practices and resisting innovations, besides treating forest as useless, less valuable or "dirty" land. Although these issues were not clearly stated by interviewed farmers, it could be an implicit (sometimes even subconscious) reason why farmers in general refused the proposal of payments to allow natural forest regeneration inside their properties. Second, the Brazilian Federal Environmental Agency (IBAMA) imposes hard sanctions and regulations regarding cutting and managing Atlantic Forest fragments. This may cause a fear among farmers that, as a consequence of allowing forest to regenerate, they will irreversibly lose a portion of their land, including the ability to extract timber for market purposes. Such concern may be even more widespread among those farmers with small properties. Third, if only a few farmers are sympathetic with the idea of giving up land to regenerate riparian forest, these may fear an economic disadvantage compared to others that use all available land for pasture. Such a pattern was proposed as an explanation as to why farmers continue to use pesticides, notwithstanding the great environmental and health costs of this practice, as those that do not use pesticides would be in a relatively unfavorable position to compete in the market (Wilson and Tisdell, 2001). These factors may partially account for the fact that three interviewed farmers currently had no cattle, but still maintain pastures, as their land would otherwise lose value in terms of opportunity costs.

Another problem arises from the fact that ecosystem services provided by forests generate not only local but also regional and global public good benefits (Costanza et al., 1997; Limburg and Folke, 1999; Pearce, 2001). Without compensation for reforestation from the beneficiaries of ecosystem services at these broader spatial scales, resulting forest stocks are likely to remain sub-optimal (Farley, 1999). Such markets for ecosystem services are already emerging through some important international initiatives, such as the proposed payments for carbon uptake by forests in developing countries (Niles et al., 2002). This may be a promising environmental conservation strategy if money so acquired could be effectively used as an incentive for the rural populations to adopt ecologically sound land management practices (Fearnside, 1997; Burgess et al., 2000). Some Brazilian NGOs (such as Pro-Natura, The Nature Conservancy, *Fundação SOS Mata Atlântica*, etc.) have increasingly pursued charges and markets for ecosystem services as a mean to stimulate on-farm forest protection and restoration of Atlantic Forest fragments (May, 2002).

In addition to the aforementioned global markets, it would be possible to create local or regional markets for some ecosystem services, such as water provision from healthy aquatic ecosystems. Recently, the creation of Ecosystem Services Districts (ESDs) has been suggested as a potential institutional mechanism to manage for ecosystem service provision (Heal et al., 2001). Institutions such as river basin authorities could serve as ESDs, coordinating land use policies in watersheds to promote the provision of flood control and water purification services. Brazilian River Basin Committees have been striving to implement such mechanisms as charges for water use (and water pollution), but this issue is still under discussion and few committees, such as that for Paraíba do Sul River, implemented water charges, but only recently. An interesting feature of such water charges is their ability to generate monetary resources that would be applied in a local level, being thus potentially more effective than federal resources in promoting local land use changes. This may become a sound approach for riparian forest conservation at the Macabuzinho River watershed, given their strategic importance to secure water provision to the city of Conceição de Macabu. Other proposals to stimulate farmers' involvement with forest conservation are governmental incentives, such as tax reductions or subsidies (Pearce, 2001), as well as devising ways of earning money from the forest through agro-forestry buffer zones around forest fragments and the economic utilization of the planted trees and shrubs (Cullen et al., 2001). Another important conservation initiative currently adopted by the NGO Pro-Natura in Macabu River watershed has been the improvement of pasture management techniques in order to enhance cattle's milk production without increasing land use for pasture (McNeely and Scherr, 2001, unpublished report).

However, although discussions about market for ecosystems services occur at a global level, the use of land and its associated impacts on natural resources and ecosystems occurs at the local level (Godoy et al., 2002). Consequently, even if there are promising market solutions to promote ecologically sound land management, achieving the ultimate goal of ecosystems' health would rely on local farmers' cooperation (Lutz et al., 1994). In order words, if local farmers manage most of the land where riparian forests should be restored, the previously mentioned initiatives, such as a global market for carbon credits (Kyoto Protocol) and regional markets for water use charges, would be successful only if local people agree to enter this new ecological market (Burgess et al., 2000). In this context, there could be at least two major shortcomings of these ecological market initiatives: first, poor people from developing countries may have difficulties in getting proposed benefits due to some constraints, such as lack of information and funding resources in order to properly participate in this ecologically oriented market (Landell-Mills, 2002). Second, usually local farmers adopt land use strategies according to direct short-term cost–benefit considerations, instead of thinking in social or ecological sustainable long-term goals (Lutz et al., 1994). According to our results, such shortcomings may have been occurring in Macabuzinho River watershed, as most interviewed landowners, albeit appreciating the forest they already have, are opposed to the idea of increasing their forestland, even if offered a proposed payment. The main reasons for the farmers' refusals of this prospect include a perceived lack of spare land and the unwillingness to assume commitments that would regulate their land use practices.

6. Conclusions

Our results indicate that farmers recognize that forests are important, but not so important that they would be willing to alter current land use patterns and allow forest regeneration at the expense of raising cattle. The interviewed farmers do recognize some, but not all, of the ecosystem services provided by forests, and not necessarily the same services or forest benefits highly prized by scientists. Farmers also failed to recognize the extent to which ecological impacts affect water quality. Based on this information about farmers perceptions, we can propose some actions and insights that may help to convince farmers to promote reforestation inside their lands. First, adequate policy and information provision should seek to increase local farmer's awareness of the direct benefits of ecosystem services, as a means to internalize these benefits in local land use practices. This could be achieved by environmental education measures, directed to the majority or the whole farmers' community, including group discussions, emphasizing the importance of ecological services while also considering the local farmer's own knowledge (Lewan and Söderqvist, 2002). This would be best achieved by dealing with those forest's ecological services that farmers already know (Table 6), instead of trying to convince them of the importance of unknown (and sometimes abstract) forest properties. Second, considering that interviewed farmers make their land use decisions based on direct market benefits and opportunity costs, incentives to forest restoration would work better if they could provide short-term economic benefits. In this sense, governmental tax reductions linked to forest regeneration and direct economic utilization of forests through agro-forestry could thus be more effective in the short-term than trying to pay some stipulated amount to farmers for the provision of ecosystem services. It would be desirable if such agro-forestry were to be based on non-timber forest products, due to current prohibitions of extracting wood from Atlantic Forest. Third, scientific research should be done in order to investigate ways in which the presence of riparian forests could enhance land productivity for raising cattle and for other agricultural activities on the Macabu River watershed. Considering that farmers themselves acknowledged such relationship between forest and agro-pastoral production, scientific data would be valuable to convince them that allowing forest to grow may indeed be a good business.

The differences between the results of interview and SVAP surveys show the complementarities of these two methods and the potential usefulness of applying this integrated approach to the study of ecological integrity and environmental impacts. For example, a survey conducted in the Macabuzinho watershed based solely on interview with farmers could not detect existing environmental impacts on stream reaches. On other hand, if only SVAP surveys were made, we would lack some important information, such as if and how farmers perceive ecological impacts, why they do not adopt more ecologically sound land management measures and to what extent they are aware of potential or actual benefits from forests. Without such information, scientists and conservationists might base their work on simplistic and erroneous assumptions about farmers' behavior, such as the assumption that they completely ignore even elemental ecological properties of forests and that they view forests solely as an obstacle to economic development. These misunderstandings could result in scientists and resource managers wasting time trying to teach farmers some concepts they already understand or treating farmers as villains who should be forced to change their land use practices, which could generate serious conflicts. Indeed, top-down approaches have often proven inefficient for environmental protection (Jim and Xu, 2002), as farmers are usually knowledgeable regarding their local environment and do not appreciate being "taught" environmental concepts by outside experts (Burgess et al., 2000).

Our study shows how a field-based multidisciplinary team can obtain interesting insights on local perceptions on ecosystem services even from a short-term and restricted case study. The empirical data generated on a pilot basis in this survey could then be complemented by additional studies encompassing other rivers and including a larger sample of farmers. However, our restricted case study provided some insights on how to use farmers' perceptions to involve them in the developing market for ecosystem services, in order to overcome some of the market failures such as asymmetrical information that may have been responsible for deforestation and ecological impacts along the Macabu River and other tropical watersheds. This case study thus suggests a promising approach to conciliate local land users' ecological knowledge and other stakeholders' concerns with water resource management linked with forest conservation and economic issues. Such an approach is particularly applicable in tropical ecosystems in developing countries where insufficient scientific data is often coupled with urgent conservation needs.

Note added in proof

The mean number of 212 cows mentioned in Results (section 4, paragraph 3, line 407), was calculated considering only the six farmers who currently have cattle in their properties (Table 1).

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Appendix A. Questionnaire used to interview farmers during the survey

Name: Age: Date:

For how long do you live here?

How many people there are in your family (live with you)?

Educational level:

Superior [ ], secondary [ ], basic [ ], illiterate [ ]

Property name:

Property size (estimate):

Which agricultural activities are currently undergone in the property (main land use)? agriculture (crops) [ ] pasture [ ] none [ ] others:

1. Where does your water come from (What is the source of water, i.e. spring, river, rainwater, etc.)?
2. What do you use the water for? Irrigation [ ] drinking [ ], cattle [ ], household [ ], other [ ]
3. Do you drink the water from your property? Yes [ ] No [ ]
   3a. If you do not drink the water, why not?
   3b. Then where do you get your drinking water?
4. Where does your sewer go?
5. Has your water color or smell changed over time? How?
6. Do you have fish in your streams?
   6a. If so, what kind of fish?
   6b. If not, have you ever had fish and if so how long ago?
   6c. Why did the fishes disappeared?
7. Have the floods changed very much?
8. Is the water supply enough for you?
9. Has the water supply changed over time? no [ ], little [ ], a lot [ ], do not know [ ]
10. Do you have forest on your land or not?
11. What kind of forest—is it original?
12. Do the forest have some relationship with agricultural production? Which ones?

Do the forest have an impact on agricultural production through:

	Good or bad?	(1 not important, 2 more or less important, 3 very important)
Shadow		
Wind-barrier		
Fertilizing		
Erosion		
Pest control		

13. Do the forest brings bad or good things to you?
    Do the forest offers:

	Good or bad?	(1 not important, 2 more or less important, 3 very important)
Wood		
Other forest resources (such as medicinal plants, firewood, fence, tools, fruits, crafts, game animals)		
Recreation, natural beauty		
Influence over the climate of the property		
Tourism		

14. Do you think that the forest is important for the water quality and quantity? How?
15. If you could clear the forest of your farm, would this be a good or a bad thing?
    15a. (for those that don't have forest) Would you like to have part of your land reforested?
    15b. (for those with forest) Would you like to have more forest inside your property?
16. Have you ever cut the forest? Yes [ ] or No [ ].
    16a. If yes, did you notice any changes after you cut the forest?
17. Why do you maintain forest on your land?
18. Do you know what was the use of the land before you moved to your farm?
19. Who is part of the changes you see in the land?
20. How frequent have there been fires here?

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