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Conservation of catchments: some theoretical considerations and case histories from Rio de Janeiro

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Abstract

Conservation has developed along two lines: protection of species and communities, and preservation of natural resources. Catchments provide the natural unit for conservation since they are the fundamental unit of terrestrial ecosystems and account for most of the flow of materials. Urban streams of the city of Rio de Janeiro are generally well protected in their headwaters by the large urban parks in steep terrain. However, the lower reaches are often very heavily impacted by sewage, channelling, etc. Fauna that require estuarine habitats for part of their life history are excluded from such streams. Ecosystem functioning in urban streams is probably changed through the loss of strongly-interacting shrimp. Leaf decomposition was found to be reduced in urban streams compared to pristine streams in one study. Conservation entities in the state of Rio de Janeiro tend to protect the mountainous areas; piedmont and coastal plain habitats are generally impacted by agriculture and habitation. Many attempts are being made to conserve catchments in the state of Rio de Janeiro; we discuss 4 case histories, which have different constraints and employ different strategies for management and conservation.

Key words: connectivity, catadromous shrimp, conservation planning and management.

Introduction

The word "conservation" has undergone subtle changes of meaning in the context of ecology and environmental management over the last century. In the first half of the twentieth century, and probably well before this, the word signified protection of resources – water, soil, forests, range-lands, fisheries and game. Governments had departments and institutions for Water Conservation, Soil Conservation, Forestry, etc. In the second half of the twentieth century, there arose a broad consciousness of loss of species and biodiversity in general. Conservation came to have a strong connection with protection of endangered species and preservation of biodiversity. The science of "Conservation Biology" arose and coopted ecological and genetic theory on questions of small populations and extinctions. The Equilibrium Theory of Island Biogeography (Macarthur and Wilson, 1967) was applied to the planning of conservation areas. This body of thinking had a strong influence on conservation

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in practice and in environmental education. To quite some extent it turned attention away from questions of landscape and ecosystem functioning and resource conservation in general.

Parallel to the developments in Conservation Biology, questions of resource depletion and loss increased exponentially in the latter half of the twentieth century. A huge amount of effort has gone into conservation of resources and ameliorating conflicts of exploitation and preservation. In this context, the term "conservation" has been used for the practices of appropriate, multi-use and non-exploitive resource usage in contrast to the term "preservation" which has to do with the maintenance of areas close to their natural state.

The two types of conservation – conservation of resources and conservation of biodiversity – are not at odds, and indeed in most circumstances are complementary and reinforcing. In the context of this paper, we can observe that the primary motivation for conservation of catchments and headwaters is usually for water supply. The conserved area is normally quite appropriate for the conservation of fauna and flora.

In other circumstances, the planning of conserved areas for biodiversity has not taken account of landscape and ecosystem functioning and the conservation objectives have been compromised. Pringle (2001) gives a cogent account of how conserved areas (principally national parks) can suffer degradation when planning and constraints ignore the limitations imposed by catchments. This may happen despite the large size of the area conserved. The problems are not only caused by impacts from headwaters, but can come from inadequate conservation of downstream areas or downstream connectivity of the aquatic system. We continue this line of reasoning and analysis here.

We perceive that the two sides of the thinking in conservation need to have more integration. In the field of conservation education, Magnusson (2001) has neatly exposed the question of why the conservation of catchments is not taught as a basic paradigm of Conservation Biology. We give further analysis and discussion to this question here.

Within the integration of resource conservation and species conservation, there are many synergistic interactions, some compromises and some conflicts. Within the broadened perspective of resource conservation we have questions of ecosystem services and ecosystem functioning. The connections between ecosystem functioning and biodiversity are being hotly debated and researched currently, but generally in the context of conservation there is little conflict of interest (Moulton, 1999). Certainly at the well-preserved (pristine) end of the spectrum of conservation, the conservation values of species (biodiversity) and ecosystem functioning go hand in hand. Indeed correct ecosystem functioning can be a tool for biodiversity preservation in cases such as fire regimes in parks and flooding regimes in wetlands. In the more utilitarian uses of the environment, such as forestry, agriculture and water storage, compromises often have to be made between conservation of biodiversity and resource exploitation. In a severely degraded situation, the engineering solution may use "environmental" principles, but will often necessarily not be concerned with biodiversity (Moulton, 1999). We recognize the need for different solutions in cases of different degrees of environmental degradation. And we present examples of links between species and ecosystem functioning.

Here we argue that the catchment forms the basic unit for terrestrial conservation because natural systems (ecosystems) are organized and integrated by the flow of materials in water (Naiman, 1992; Naiman *et al*., 1995; Moulton and Souza, 2006; Moulton and Wantzen, 2006). We discuss and analyse conservation configured about catchments – that is, of the land area contained by the catchment. And we discuss questions of conservation of the actual streams and rivers of the catchment. The two aspects are very much interlinked.

We take our examples from the city and state of Rio de Janeiro, Brazil.

History of conservation in Rio de Janeiro

The city of Rio de Janeiro provides an early example of enlightenment and action in catchment conservation. The city expanded greatly in the early part of the nineteenth century when the Portuguese king, Dom Pedro I, set up court and the city became the capital of Brazil. Much of the forest of the mountains within the city was transformed for agricultural purposes, mainly plantations of coffee, tea and sugar cane. The inhabitants of the city perceived, however, that the loss of forest had detrimental consequences for the environment. The water supply for the city derived from mountain streams within the city, and it became irregular with the loss of the forest – it diminished in times of little rain and when heavy rains fell there was flooding and obvious erosion. The oppressive heat was also blamed on the loss of the forest. Emperor Dom Pedro II was petitioned to do something about the problem, and he decreed a program of re-afforestation. This was undertaken principally by Major Michael Archer, who planted approximately 60,000 trees between 1860 and 1874. As well as the direct re-afforestation, much of the area revegetated naturally after the plantations and habitation were removed. The measures for protection of the catchments and forest appear to have been effective, although the Tijuca National Park was declared only in 1961.

Urban parks of Rio de Janeiro

As a legacy of the steep geography and the enlightenment of Dom Pedro II, the city of Rio de Janeiro possesses the two largest urban forests in the world – the famous Tijuca National Forest (3,300 ha) and the lesser known but even larger State Park of Pedra Branca (12,500 ha). Both parks are entirely surrounded by the city of Rio de Janeiro. They suffer from illegal settlement and other human activities and both are subject to diverse and diffuse impacts of the surrounding conurbation. But because of their size they contain a large biodiversity and provide a range of ecosystem services and aesthetic values. The main water supply for Rio de Janeiro is piped from distant catchments, but there are still many local water schemes that supply local suburbs.

The streams that issue from the parks generally have good to excellent quality water, but are all heavily impacted by the conurbation in their lower reaches. Many streams receive raw sewage from slums shortly after they leave the parks. Most have lost a large amount of their riparian vegetation and their immediate catchment is greatly impermeabilized compared to the natural situation. Most have greatly altered water course in their lower reaches, with channelization and underground galleries in many cases.

The heavily impacted lower reaches would appear to require strong engineering measures to remedy the problems of basic sanitation and pollution. In some areas there appears to be potential for restoration of the streams in a natural configuration, but for many situations the demands for storm-water runoff and the loss of open space will mean that "restoration" of many of the lower reaches will remain highly artificial. We may ask, however, how the degradation of the lower reaches of the streams affects the ecology of the relatively well-preserved upper reaches.

Impact going against the flow

The streams of the southern part of the Parque Estadual da Pedra Branca (PEPB) arise in relatively well-protected forest and have various connections with coastal lagoons and the sea (Figure 1). The more northern streams, Rio Pequeno, Rio Grande, Rio Engenho Novo, flow through densely settled suburbs and flow into the coastal lagoon Jacarepaguá. The southernmost streams, Rio Paineiras and Rio Sacarrão, flow into a broad tidal canal that connects to the sea. Fauna that require the sea or estuary for part of their life cycle are eliminated from the streams that have lost their connection with the sea or estuary (Moulton *et al*., 2000). Catadromous species of shrimp (*Macrobrachium olfersi, M. acanthurus, Potimirim glabra*) have apparently been lost from the streams that are badly polluted in their lower reaches and which no longer provide a viable connection between the upper unpolluted reaches and the estuary (Table 1). One not-catadromous species, *Macrobrachium potiuna,* is found in the upper reaches of some of the streams in which the catadromous species have apparently been lost. Certain species of fish, *Characidium*, *Trichomycterus*, appear in the upper, little-impacted reaches (Table 1). Likewise certain molluscs are found only in the little-impacted parts (Braun, 2005). On the other hand, larger populations of fish and molluscs are found in the lower, polluted reaches. They are principally introduced species – the guppy *Poecilia reticulata*, and the snails *Melanoides* and *Physa*.

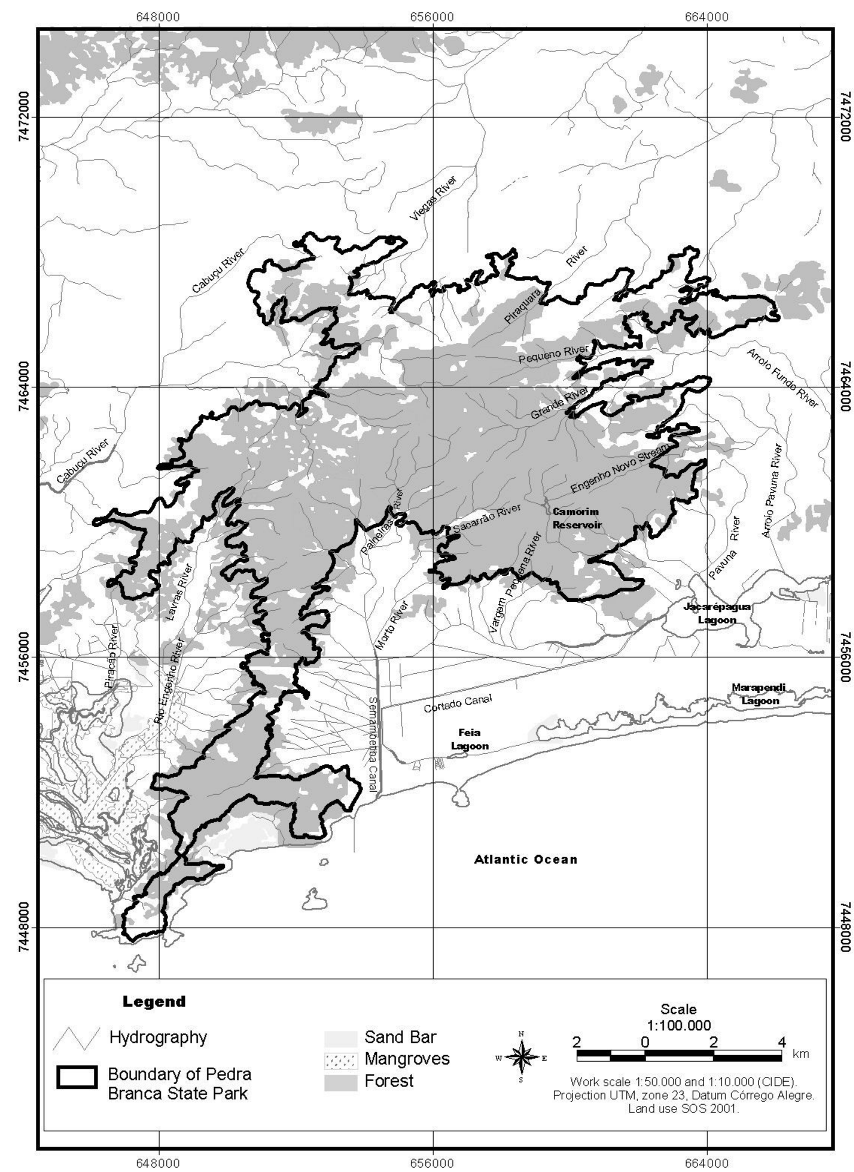

Figure 1. Catchments of Parque Estadual da Pedra Branca and surrounding areas.

The shrimps *Potimirim glabra* (Atyidae) and *Macrobrachium olfersi* (Palaemonidae) have strong interactions with other fauna and with periphyton and sediments (Moulton *et al*., 2004; Souza and Moulton, 2005). It is likely that their loss from the upper reaches of the streams has produced changes in the community dynamics and properties of the substrate. A similar pattern of loss and reduction of catadromous shrimps and the probable ecosystem consequences was reported for streams in Puerto Rico (Pringle, 1997; Greathouse *et al*., 2006).

It is quite likely that species other than strictly catadromous species have been lost from these urban streams due to the pollution of the lower reaches and the loss of connection with coastal lagoons (Moulton *et al*., 2000). In February 1996 a large spate in Rio Grande caused catastrophic change to the bed of the river and probably washed many species of fish, shrimps and other macroinvertebrates downstream, causing their local extinction. *Macrobrachium potiuna* was probably present before the spate and appears not to have recolonized. Anecdotal evidence suggests that several fish species were also lost. Presumably such species would have recolonized from the coastal lagoon or other downstream parts of the river system if they had not been severely polluted.

Many of the streams have small dams with active extraction of water for domestic supplies. The size of the reservoirs is usually quite small and the only exception is the dam on Rio Camorim, which produces a medium-sized lake. The dams interrupt the continuity of the streams and the extraction of water can markedly reduce stream flow (unquantified person observation). We have not analysed the effects of these small, low-head, dams, but by extrapolation from studies elsewhere we can expect that they negatively affect migratory fauna and ecosystem functioning of the streams (Benstead *et al*., 1999, March *et al*., 1998; Greathouse *et al*., 2006).

Ecosystem functioning in relatively intact urban streams vs pristine streams

Apart from the abovementioned "impacts going against the flow", the upper reaches of these urban streams appear relatively intact. The forest cover is generally high, although in most parts the forest is obviously secondary. In most catchments there is some human impact and there are small settlements and isolated houses within the park, which plant bananas, manioc and other crops. Atmospheric pollution probably contributes some impact, although there are no specific data. Water quality in the streams of the park appears good. We can ask whether the functioning of the stream ecosystem has changed under these relatively light impacts.

Moulton and Magalhães (2003) studied leaf decomposition in two urban streams (Rio Grande and a closed-canopy tributary of Rio Grande) and compared the rate of decomposition and associate macroinvertebrates with two streams in not-urban Atlantic rainforest. Rate of leaf processing was approximately twice as fast in the not-urban streams compared to the urban streams but the richness and diversity of the fauna (macroinvertebrates) associated with the leaf packs was not significantly different at the order level. The experiment provided preliminary evidence of a reduction in ecosystem functioning in urban streams, as represented by leaf decomposition. It also questioned the assumption that biodiversity (richness of macroinvertebrates) is a more sensitive indicator of impact than is ecosystem functioning.

Conservation of catchments in the state of Rio de Janeiro

The state of Rio de Janeiro contains a significant portion of the remaining Atlantic rainforest of Brazil. Although it has lost a large percentage of the original forest, approximately 16% remains and much of this is in relatively large areas (S.O.S. Mata Atlântica, 2002). Part of the reason for the preservation of the forest is that the majority of it occurs in steep mountainous terrain, which is difficult to use for agriculture or grazing.

Table 1. Distribution of shrimps and fishes among 7 streams of the urban park Parque Estadual da Pedra Branca. + = present; - = absent.

Species	Paineiras	Saccarão	Vargem Grande	Camorim	Engenho Novo	Grande	Pequeno
Shrimps							
Macrobrachium olfersi	+	+	-	-	-	-	-
M. acanthurus	+	+	-	-	-	-	-
M. potiuna	-	-	-	+	+	-	+
Potimirim glabra	-	+	-	-	-	-	-
Fishes							
Poecilia reticulata	+	+	+	+	+	+	+
Astyanax hastus	+	+	-	+	+	-	+
Trichomycterus	-	-	-	-	-	+	+
Characidium	-	-	-	+	-	-	-
Shizolecis guntheri	+	+	-	-	-	-	-

As mentioned above, conservation efforts commenced very early in Rio de Janeiro city, with the reforestation of Tijuca forest in 1861. There was a movement to make national parks as early as 1876, inspired by the declaration of Yellowstone National Park in USA in 1872. But it was only in 1937 that the Itatiaia National Park (11,900 ha) was declared – as the first national park in Brazil. In the second half of the twentieth century many conservation areas were declared in various categories of protection – national parks, state parks, municipal areas, APA (Área de Proteção Ambiental – Environmental Protection Area), RPPN (Reserva Particular do Patrimônio Natural – Private Natural Heritage Reserve). At present, the state of Rio de Janeiro has 43 conservation areas, which represent 10% of the area of the state. The majority of the conserved area is in steep, mountainous terrain, where forest remains. Often this coincides with the upper parts of catchments, and serves to protect headwaters. It is difficult to determine the prime motivation for the declaration of conservation areas, because usually there are several reasons cited, but 27 of the 43 conservation areas of the state have as an objective the preservation of headwaters.

Lower areas of the state have not been preserved to the same extent. Grazing, agriculture, urbanization and industry have heavily impacted the piedmont transitional zone, valleys, coastal plain and coastline. Likewise, the lower parts of the streams and rivers have generally been heavily impacted. The consequences for conservation of species are that many of the endangered and extinct species are in these lower areas. Jenkins and Pimm (2005) found that many species of endangered birds inhabited piedmont areas of forest in Rio de Janeiro. In streams and rivers, a higher diversity of macroinvertebrates, especially Ephemeroptera, was found in a 4th order stretch of a river (Rio Macaé, Figure 2), and certain species were restricted to lower parts of the river (Baptista *et al*., 2001; Buss *et al*., 2004). The impacts that occur in most of the lower reaches of rivers in the state of Rio de Janeiro are likely to threaten many of these species (Moulton *et al*., 2000).

As well as the strictly habitat specific aspects of this problem, there is dynamic interaction with adjacent areas. This is very obvious in the fluvial environment, where the upstream impacts are carried directly to downstream areas by water flow. It can also be an important factor in the aquatic-terrestrial interaction in the riparian zone and beyond (Wantzen *et al*., 2006). In the strictly terrestrial environment, the interactions between adjacent zones are seen particularly in mobile organisms such as birds; many bird species that live and nest principally in upland forest, but forage at certain times of the year in lowland areas. Mobile organisms in the aquatic environment can suffer the loss of fluvial continuity (Moulton *et al*., 2000). In some cases, the mobile organisms are important agents in ecosystem functioning. We cited the catadromous shrimp above (Moulton *et al*., 2004; Souza and Moulton, 2005), and these are well known from Central America and the Caribbean (Pringle and Blake, 1994; Pringle *et al.,* 1999; Greathouse *et al.,* 2006). We can also mention armoured catfish in Panama (Power *et al.*, 1989) and the characin, *Prochilodus mariae*, in Venezuelan piedmont streams (Flecker, 1996), which act strongly on the substrate as well as migrating along the rivers. The armoured catfish of Rio de Janeiro possibly have similar effects (see Table 1). Other predatory fish may have strong, cascading interactions (personal observations, Souza *et al*., 2001).

The above argues for the conservation of whole catchments. Conservation planning should try to incorporate the conservation of representative catchments in their entirety when possible, and ameliorate pollution and other impacts when preservation status is not possible (Moulton, 1999; Moulton and Souza, 2006). The state of Rio de Janeiro does not have a whole catchment and river that is well preserved, but steps are being taken to remedy the situation. We present 4 case histories, which illustrate problems and potential solutions in catchment-based conservation in Rio de Janeiro.

Four case histories

The state of Rio de Janeiro has several mountain chains, which run parallel to

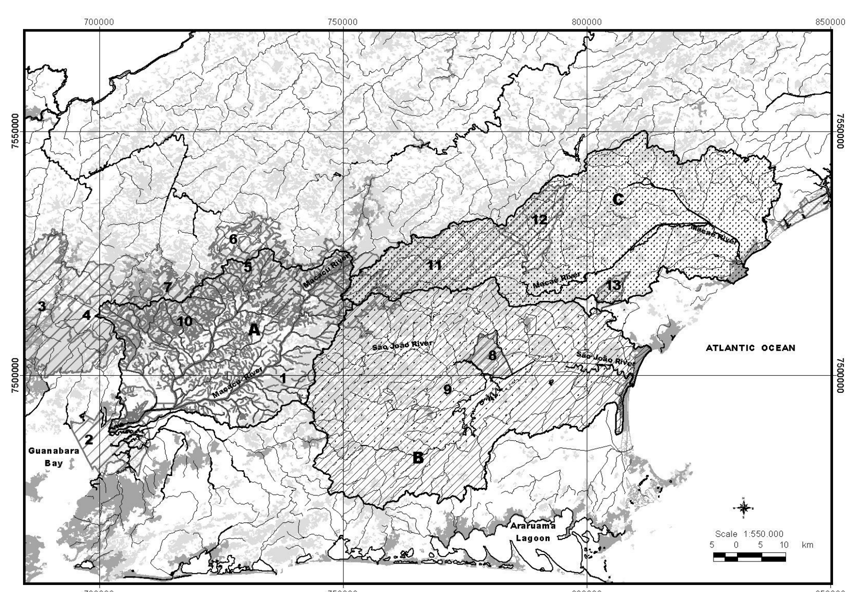

Figure 2. Three catchments of Rio de Janeiro. A – Bacia do Rio Guapiaçu e Macacu; B- Bacia do Rio São João.

the coast. Streams form in the mountains and cross the coastal plain, sometimes forming freshwater or brackish lagoons and often running into the sea in mangrove areas. Apart from the Rio Paraiba do Sul, which runs almost the full length of the state between the parallel mountain ranges, all other rivers are relatively small and those that drain the eastern faces of the mountains run more or less directly into the sea.

Case 1. Catchment of the Rio Macaé

The Rio Macaé catchment arises in well-preserved Atlantic rainforest in the mountains of the coastal range (Figure 2). Part of its headwaters are in conservation status "APA" (Área de Proteção Ambiental, labelled 11 and 12 in Figure 2), which protects the environment while allowing houses on large properties, guesthouses, camping areas and certain types of agriculture and animal husbandry, including trout hatcheries. Other parts of the headwater catchments do not have conservation status, but are currently well preserved because of the mountainous terrain. The river and riparian vegetation are relatively intact at its 4^{th} order (above ~1,000 m), but becomes polluted by the town of Nova Friburgo at its 5^{th} order (~650 m) (Baptista *et al.,* 2001). As the river progresses to the lowlands and across, the coastal plain agriculture, grazing, loss of riparian vegetation and settlement increasingly impact it. At its mouth it is channelled and severely impacted by the town of Macaé. The important conservation area of sand-plain vegetation, "Parque Nacional da Restinga de Jurubatiba" lies a few kilometres to the north and disconnected to the river (labelled 14 in Figure 2). The conservation status of the catchment ranges from excellent in the headwaters, to being seriously compromised by the pollution caused by the towns along its course and by the lack of protection of the river in coastal plain and mouth.

Case 2. Catchment of Rio São João

The catchment to the south of Rio Macaé is that of Rio São João. Geographically, it is similar, originating in the same mountain chain, crossing the same coastal plain and flowing into the sea. It is somewhat different in having more input from lower mountains/hills of the coastal plain to the south of the Serra das Orgãos (Figure 2). The catchment contains some important conservation areas in the coastal plain – Reserva Biológica Nacional Poço das Antas, which contains the primary area of conservation of the Golden Lion Tamarin (*Leontopithecus rosalia*), and other Private Natural Heritage Reserves (RPPN). The mouth of the river, Rio São João, is relatively well preserved, and the small township of Barra de São João is much less impacting than large town of Macaé. Probably because of the perceived importance of these reserves and the possibility of conserving an integrated catchment, this catchment has been the subject of the first catchment conservation plan of Rio de Janeiro. In 1999 a group of interested parties formed a consortium to plan and manage the region (Consórcio Intermunicipal para Gestão Ambiental das Bacias da Região dos Lagos, do Rio São João e Zona Costeira), and in December 2004 the Rio São João Catchment Committee was formalized (http://www.lagossaojoao.org.br). The catchment of Rio São João has been given APA status. Included in the conservation plans is the restoration of the lower reaches of the river that were channelled for irrigation; the proposal is to return the river to its original sinuous course. The coastal plain contains much small-scale agriculture and aquaculture (of *Macrobrachium* shrimp and fish), and the water resource will certainly have multiple uses. The reservoir of Juturnaiba, which interrupts the course of the Rio São João, is the focus of intense interest because it is important for the water supply of a large coastal region. The conservation of the river will involve many compromises with the necessities of multiple uses, and the framework of the Catchment Committee provides the means for addressing and resolving these issues. The community of conservationists will watch with great interest the progress and results of this experiment.

Case 3. Catchment of Rio Guapiaçu-Macacu

The next catchment to the south is that of Rio Guapiaçu-Macacu (Figure 2). It is different to the previous two in that it flows into Guanabara Bay – the large harbour of Rio de Janeiro. At its mouth is the major area of conservation of mangrove and estuarine environment of Guanabara Bay (APA Guapirimim). The headwaters arise in several important conservation entities of different types – national park, state park, ecological station. It would seem logical to try to link the preserved upper reaches with the reserve at the mouth of Rio Macacu, but the intervening area is more densely inhabited than in the other two cases, above. An imaginative solution has been devised in which the riparian zone of the river, 150 m on both sides for the main rivers, and 50 m for tributaries, has been declared an APA – Área de Proteção Ambiental da Bacia do Rio Macacu. This initiative arose from the explicit recognition of the potential importance of conserving and restoring fluvial connectivity, along with the preservation of the downstream estuarine environment. The dendritic APA is an experiment that will be watched with great interest. It is being actively researched and a management plan is being coordinated by the NGO Instituto BioAtlântica (http://www.bioatlantica.org.br/informativos2/infoserrasaguas.pdf). The implementation and maintenance of the protected area provide great challenges; agriculture and grazing have modified much of the original riparian vegetation, and viable alternatives will have to be found for farmers. In theory, the protection of the riparian zone offers great protection of the river ecosystem. Brooks (1999) found that protection of a narrow riparian margin had a disproportionately large benefit for the river. It is also thought that the riparian margin will provide an important corridor to link the estuarine protected area (APA Guapimirim) with the coastal plain and mountain parks (Parque Estadual Três Picos, etc.).

Case 4. Southern catchments

Further to the south are large areas of preserved mountains – APA de Petrópolis (labelled 3 in Figure 2), the national park Serra dos Órgões (labelled 4) and the state park Tinguá (off the map). These form essential parts of the corridor of protected areas of the Biosphere Reserve of the Atlantic Rainforest. Unfortunately, the streams that issue from these areas flow through heavily inhabited and industrialized areas of the city of Rio de Janeiro, before they flow into Guanabara Bay. The potential for restoring these reaches to their "natural" state is remote, and it would appear that efforts should be concentrated, at least in the immediate future, on engineering solutions to the problems of gross pollution, which in turn affect the bay.
These four cases provide an interesting natural experiment in stream and river conservation. The first, of the catchment of Rio Macaé, provides the unfortunate "control" where river connectivity and basic conservation are not in place, except for the high elevations. The second and third cases provide interesting and contrasting solutions, the success of which will be judged with time. The fourth situation is one in which "biodiversity conservation" gives way to environmental engineering (Moulton, 1999).

Legislation and planning

At the national level, Brazil has strong legislation for the rational use of its inland water resources – the Lei das Águas (Lei 9433/97, 1997). In 2001 the National Water Agency (ANA) was set up with the explicit mandate to promote the formation of bodies to oversee the rational use of water resources based on catchments – the "Comitê de Bacia". The committees are formed from all interested parties, from the government, private sector and the public. The structure seems to be strongly oriented towards water allocation and quality rather than conservation, and it seems somewhat ironic that such a potentially useful structure does not have more input from ecologists and limnologists and an alignment with conservation (Moulton, 2002).
At the state level, the mechanisms for planning and management based on catchments are in place. The first committee – for the Bacia do Rio São João – seems to have started well. Apart from the actual catchment committees, there are legislation and mechanisms for riparian conservation outside conservation entities (including Agenda 21). Legislation on water pollution and mechanisms for requiring water treatment appear adequate. The implementation of the mechanisms and the enforcement of the laws are generally weak, however.
The other side of Conservation – of species and biodiversity – is well represented by plans and projects. The most ambitious and over-arching plan is that of the Biosphere Reserve of the Atlantic Rainforest, which includes other states. In Rio de Janeiro there is an ambitious plan to link conservation entities into a "corridor" by purchasing essential areas and promoting the formation of private reserves. Brazilian legislation allows for the formation of RPPNs (Reserva Particular de Patrimônio Nacional) – areas of private land that the owners place in legal conservation status. In the past, the plans for corridors were made on a two-dimensional basis, without consideration of catchments (Reserva da Biosfera da Mata Atlântica, 1994). More recently in the literature of the Biosphere Reserve, cognisance has been given to questions of aquatic conservation (Lino and Dias, 2003). Just how this is put into practice remains to be seen.

Conclusions

Rio de Janeiro provides an interesting scenario of conservation needs and potential solutions. Its rich biodiversity and relatively intact forests call for strong measures in biodiversity conservation. But these need to be integrated with conservation of resources, and we argue for conservation plans based on catchments. We provide evidence and plausible reasoning for why fluvial connectivity is important both for preservation of the aquatic system and for the associated terrestrial areas.
Rio de Janeiro and Brazil in general have the necessary environmental legislation for integrated conservation and environmental management based on catchments. The implementation and enforcement of the plans is difficult. We take heart from the active programs that are being pursued at different levels and with diverse mechanisms.

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