# Challenging issues of urban biodiversity related to ecohydrology

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(With 12 figures)

## Abstract

This paper aims to outline challenging issues of urban biodiversity in order to address yardsticks related to ecohydrology, and with a complementary approach to eutrophication impacts. The vision of environmental services, urbanization's consequences and management aspects of water governance are also depicted. Factors of river restoration, environmental tradeoffs and socio-cultural constrains are envisaged through concept questions towards emerging aspects that figure out methodological guides, strategic challenges for stakeholders and inter-disciplinary opportunities. Examples from case studies on restoration and management, from experiences and lessons learned, are enclosed, with brief discussions and literature citation.

*Keywords:* ecohydrology, urban biodiversity, urban waters.

## Desafios da biodiversidade urbana relacionados com a ecohidrologia

## Resumo

Este artigo aborda desafios sobre a biodiversidade em ambiente urbano com o propósito de apontar uma relação com a ecohidrologia e com especial aproximação aos problemas recorrentes da eutroficação. A visão de serviços ambientais, as conseqüências da urbanização e os aspectos da gestão para uma governança em torno dos recursos hídricos são também apontados no trabalho. Fatores como a recuperação ambiental dos rios, as compensações ambientais e as restrições sócio-culturais são mencionadas usando perguntas conceituais que direcionem aspectos emergentes, no sentido de exemplificar guias metodológicos, desafios estratégicos na negociação junto aos atores e às oportunidades interdisciplinares. Alguns exemplos extraídos a partir de estudos de caso são mostrados, em especial de experiências e lições apreendidas, com discussões e citações da literatura atual do tema.

*Palavras-chave:* ecohidrologia, biodiversidade urbana, águas urbanas.

## 1. Introduction – How Challenging Issues Could Be Envisaged to Urban Biodiversity?

According the Convention of Biological Diversity (UNEP, 1992), biological diversity means the variability among living organisms from all sources including, inter alia, terrestrial and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems". Biodiversity is a composite measure of the number of species, in terms of species richness, and the number of individuals of different species, in terms of relative abundance. Most ecosystem services, such as the provisioning of food or clean water, depend on the presence of sufficient numbers of individuals of each species. In urban areas, these services will decline at smaller scales, for instance at the catchment, with the local extirpation or reduction of populations, long before global extinctions take place at the watersheds or even river basins. For other ecosystem services, and in particular those that rely on genetic diversity, the central issue is species richness. For example, the provisioning of new pharmaceutical drugs to cure current and future diseases and the maintenance of genetic resources to improve current crop varieties are not directly related to the abundance of individuals within a species. In these instances, the provision of services only ceases after global extinction (see more discussions details in Gregory et al., 1991; Williams et al., 1997; Ward and Tockner, 2001; Sala et al., 2005; among others).

The common perception that urban areas are kinds of such old ecological, well-known habitats being rapidly converted into new human, poor-understood settlements is increasing (UNESCO-WMO, 2001). However, the scientific literature of urban diversity is sparse. Gyllin and Grahn (2005) and Alvey (2006), in terms of promoting biodiversity in the urban forest, raise the questions to whether the tools that urban planners have at their disposal are sufficient and, if not, what the potential consequences of biodiversity integrated into the urban planning process might be. These authors outline the situation when planners in different municipalities take, individually, the same routine measures to enhance local biodiversity, thereby decreasing biodiversity on a regional scale. This problem is special crucial because risk increases with tendency to view biodiversity purely as a quantity disregarding local qualities and also because the numbers of species at urban environments are not high enough. To address taxonomy ecology, Hawksworth (1995) presents a complete set of measurement methods of biodiversity, along with a discussion on measurement and estimations. Others authors, i.e. Sukopp and Weiler (1988), Frey (1998), Müller (1998), Weber and Bedê (1998) and Sala et al. (2005), among others, present methods directly aimed at urban biodiversity planning with focus on concept of biotope/habitat. The problem with such approaches is that biotopes need to be calibrated with regard to the composition of species, to make investigations comparable and informative. Without such a calibration, results rely too on documented knowledge about biotope types. Such knowledge about urban biotopes is very limited, which leaves prejudice and downright guessing as very unsatisfactory solutions. Another problem with biodiversity is its dependence on scale of hydrological processes (Mendiondo and Tucci, 1997; Sala et al., 2005) which is also connected with the question whether biodiversity is a quantity or a quality indicator, either from experiments or modeling (see works of Benka-Coker and Ojior, 1995; Tucci, 1998; Hulse et al., 2000; Shanahan et al., 2001; UNEP, 2003; Wanga et al., 2005; Bottino and Mendiondo, 2008).

This paper therefore addresses the topic of urban biodiversity as a hot-spot in terms of challenging issues more related to not only ecological but even hydrological aspects, especially regarding eutrophication factors. Accordingly, Table 1 shows some of these challenging issues on biodiversity loss at uplands and eutrophication

**Table 1.** Challenging issues on biodiversity loss at uplands and eutrophication impacts at lowlands to schedule with urban stakeholders. Source: Mendiondo and Tundisi (2007).

| Keypoint | Working questions and hypotheses |
|---|---|
| Innovation | • What decentralized innovations are achievable to maintain the eco-hydrology of the system “drainage area, floodplain and water body” of urban river basins? |
| | • How could in-flow needs help “catching” nutrients on uplands and floodplains to mitigate downstream eutrophication and river regime alteration? |
| Ecological Services | • How the ecological services of urban water bodies could to be valuated? |
| | • How does urban ecosystem degradation cause significant harm to human well-being? |
| Trade-offs | • How ecological services are meaningful from biodiversity to the human well-being? |
| Scenarios | • What scenarios are suitable to reduce biodiversity loss and eutrophication impacts? |
| | • How will global change affect biodiversity loss of urban uplands and reservoirs? |
| Water governance | • What yardsticks on biodiversity should underpin urban sustainability for stakeholder conflicts, especially with relationships from upstream to downstream areas? |
| | • Could protocols become scientific ways to aid transboundary problems of biodiversity loss and eutrophication of urban areas in terms of community participation? |
| | • Would potential pressure water conflicts make biodiversity loss accelerate at most? |
| Lessons learned | • How past experiences from indigenous knowledge should be learned to mitigate future biodiversity loss rate at fast growing eutrophication near cities and metropolitan areas? |
| Managing costs | • Which risks of biodiversity loss are to be coped with institutional accountability? |
| | • What insurance can cope with risks of increasing biodiversity loss at the long term? |
| | How could protocols be implemented under water plans to better manage urban basins under, or in progress of, biodiversity loss and with eutrophication crisis? |
| | • Could the specific costs of today and future water demands on urban water bodies under progressive biodiversity loss be estimated at nested catchment scales? |
| | • How does adaptive policy collaborate to maintain water quality from biodiversity? |
| Research | • How to integrate remedial measures ecohydrology for urban biodiversity maintenance? |
| | • How does floodplain play as retention basin of nutrient loads? |
| | • How to relate trophic factors with ecohydrology of floodplains? |
| Capacity building | • How should ecosystem services assessment empower the less resilient groups? |
| | • How could adaptive management assess the water “compromise” on urban flows? |
| Pilot projects | • What right actions to what audience should assure biodiversity enhancement through adaptive participatory management ? |

impacts at lowlands to schedule with urban stakeholders (adapted from Mendiondo and Tundisi, 2007). Likewise, the Figure 1 shows temporal scales at which urban potential impacts should stabilize with a wide range of circumstances which affect biodiversity loss. From this figure, it is evident that eutrophication impacts on urban biodiversity could remain at the long-term related with other threats (Benndorf, 1995; Bernhardt et al., 1985) and that experimental limnology strategies where eutrophication exists (e.g. Arcifa et al., 1995; Riemann and Søndergaard, 1986) could be adapted in order to restore altered urban conditions (Moss, 1990; Sutcliffe and Jones, 1992; Lewis Jr., 1996; Mendiondo, 2000a; Mendiondo et al., 2000) and the respective environmental services and impacts (Straskraba and Tundisi, 1999).

## 2. Ecosystems Services of Urban Biodiversity

The Table 2 points some impacts derived from scenario development using ecosystem services of green belts for freshwater biodiversity of metropolitan regions. The comparison of expected responses of forest-, water-body- and urban ecosystems' services to changes in biodiversity appears in Table 3 (adapted from Sala et al, 2005). In this table, the responsiveness indicator is described in an arbitrary scale. Higher values in Table 3 describe services and ecosystems that are performed by species in upper trophic levels and therefore are brittle in comparison with other services. Otherwise, lower values of Table 3 point out ecosystems performed by species in lower trophic levels and more resilient. Some less resilient environmental service is indicated with an asterisk, when either forest or water body is converted into urban ecosystem which accelerates endangering species, with increasing eutrophication and decreasing resiliency. Also Tundisi (2006), Zalewski (2000) and Zalewski and Wagner (2004, p. 91) discuss eutrophication in continental waters and frequent thresholds of trophic states according to density, total number of bacteria, biomass of baterioplankton and production and respiration of bac-

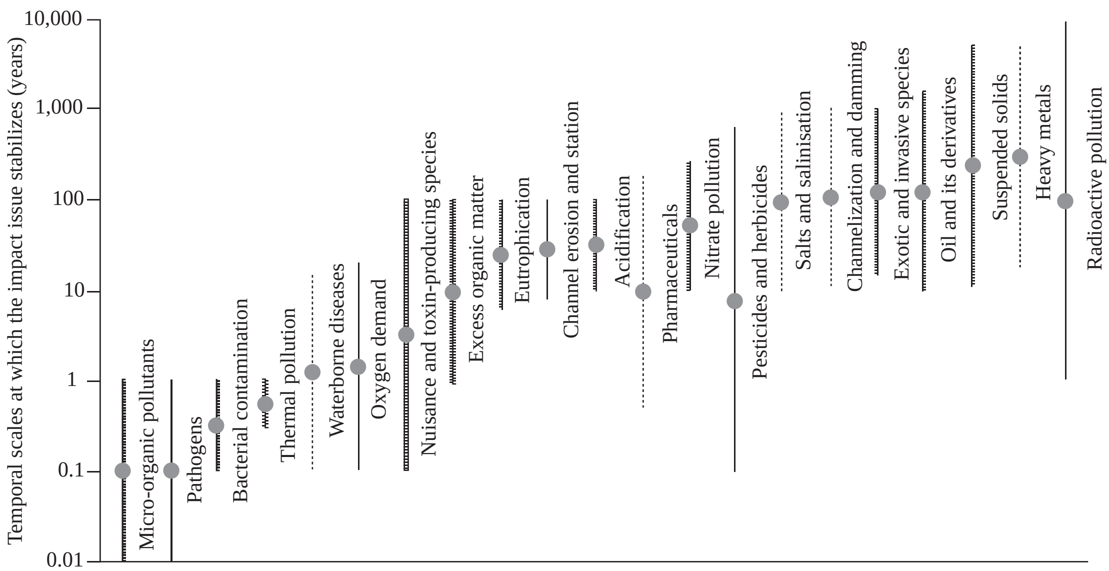


**Figure 1.** Temporal scales of urban potential impacts on biodiversity loss. Eutrophication impacts could remain at the long-term related with other problems.

**Table 2.** Impacts (positive ▲, negative ▼ or constant ◄►) derived from scenario development using ecosystem services of green belts for freshwater biodiversity of metropolitan regions.

| Ecosystem service | Environmental good/ service | Impacts on environmental goods/services |
|---|---|---|
| Supporting | Ecological processes and biodiversity | Forests as ecological corridors ( ▲) and preserving headwaters (▲). |
| Provisioning | Groundwater and surface water supply | All urban people, with collapse risk in public water supply (▼) Correlation between forest and water quality and quantity (◄►). |
| Regulating | Climatic regulation | Urban temperature rising (heat islands) influence rainfall patterns and lead to heavy urban floods (▼). |
| | Soil protection and run-off regulation | Revitalized forests prevent soil erosion and minimize floods (▲) |
| Cultural | Social use | Lack of green areas (◄►) invokes peri-urban belts as an alternative for the population to be contact with healthier environment (▲). |

**Table 3.** Comparison of responses of forest-, waterbody- and urban ecosystems' services to changes in biodiversity. Responsiveness indicator is described in an arbitrary scale of 1-5; on the one hand, higher values are describing services and ecosystems that are performed by species in upper trophic levels and therefore are brittle in comparison with services; on the other hand, ecosystems with lower values are performed by species in lower trophic levels and are resilient. Asterisk * points a less resilient service when either forest or water body is converted to urban ecosystem which accelerates endangering species and increasing eutrophication. Source: adapted and corrected from Sala et al. (2005).

| Ecosystem services | Forest | Water bodies | Urban |
|---|---|---|---|
| Provisioning | | | |
| Food | 5 | 5 | 1 |
| Biochemicals and pharmaceuticals | 3 | 3 | 0 |
| Genetic resources | 3 | 3 | 0 |
| Fuelwood | 1 | 0 | *1* |
| Fiber | 1 | 5 | 1 |
| Ornamental resources | 5 | 5 | 0 |
| Freshwater | 1 | 3 | *1* |
| Regulating | | | |
| Air quality | 1 | 1 | *2* |
| Climate regulation | 1 | 1 | *3* |
| Erosion control | 1 | 5 | *3* |
| Water purification and waste treatment | 2 | 1 | *3* |
| Regulation of human diseases | 3 | 4 | *5* |
| Biological control | 4 | 5 | *4* |
| Detoxification | 3 | 1 | *3* |
| Storm protection | 3 | 3 | 1 |
| Cultural | | | |
| Cultural diversity and identity | 4 | 5 | *5* |
| Recreation and ecotourism | 4 | 5 | *5* |
| Supporting | | | |
| Pollination | 3 | 0 | *3* |
| Soil formation and retention | 1 | 1 | *2* |
| Nutrient cycling | 3 | 1 | *3* |
| Provision of habitat | 3 | 4 | *4* |

terioplankton (P/R ratio). In urban areas, a great range of possibilities of trophic conditions occur involving threats to the security of economic, societal and health sectors. Moreover, investment and maintenance costs are increasing at urban settlements according to the area occupied by dwellers and the total inhabitants living on. Thus, urban water security management related to the risk of biodiversity loss is commonly approached to handle stakeholder participation using principles, types of policies, derived costs and action plans (Table 4, adapted from Mendiondo, 2005). For example, a perceptual approach of local environmental projects to attend ecological factors of biodiversity loss at urban micro-catchment of *Tijuco Preto*, São Carlos, Brazil is presented in Figure 2.

## 3. Ecohydrological Categories for Urban Biodiversity

Ecological features of urban freshwater biodiversity can be addressed over landscape continuity through structural and biological features of river corridors. The Figure 3 outlines three study-levels according to measures and scenarios, thereby regarding urban planning, flood-protection and river restoration. In this figure, left margin (upper part) and right margin (bottom part) outline topographical delineation with frequency of water logging (darkness intensity), river flux and connections (arrows) and possible ecological interactions (dotted lines). Simple and double winged lines outline, respectively, low-flow and high-flow terraces of alluvial floodplain. Cost and efficiencies of each approach grow, from the left-side to the right-side of the Figure 3. For sustainable management of peri-urban biodiversity and to reduce eutrophication at floodplains, the third level addressed in Figure 3 attempts to ecohydrological categories which are detailed in the Table 5, adapted from Almeida-Neto and Mendiondo (2008), and with concepts incorporated from a wide range of theoretical and experimental works (e.g. Vannote et al., 1980; White and Pickett, 1985, Hill and Platts, 1991; Reynolds, 1992; Kareiva and Wennergren, 1995; Tundisi, 1999; Straskaba and Tundisi, 1999; Janauer, 2000; Dale et al., 2000; Mendiondo, 2000b; Walker et al., 2004; Bunn and Arthington, 2002; Zalewski, 2000; Zalewski and Wagner, 2004; Hannah et al., 2007). All these categories are ranked in accordance with principles of continuity, dynamics, resilience, vulnerability and diversity (see also Holling, 1973; Holling and Gunderson, 2002; Margalef,

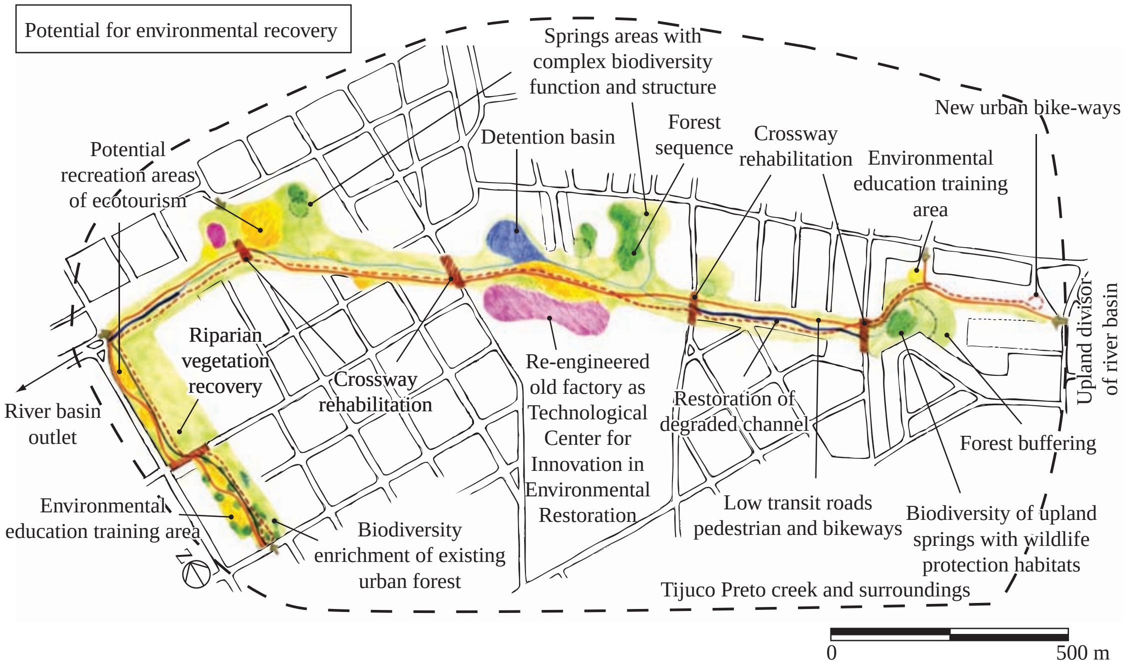


**Figure 2.** A perceptual approach of local environmental projects to restore biodiversity loss at urban micro-catchment of *Tijuco Preto* Creek, Sao Carlos, Brazil. Total specific cost of biodiversity restoration project was calculated in 2.5 million US$/km$^2$ of drainage area of river basin. Total environmental services of urban catchment are estimated in ca. 28 to 33 million US$/km$^2$. Source FIPAI-PMSC (2005).

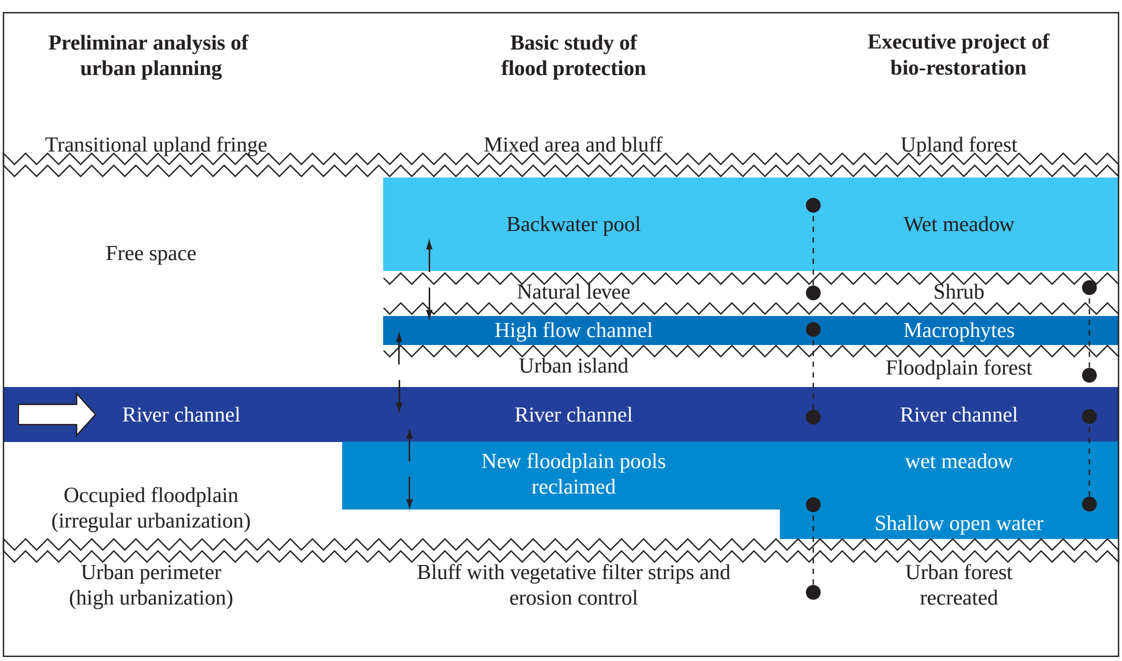


**Figure 3.** Three approaches of urban river restoration with urban planning, flood protection and biodiversity enhancement (from Mendiondo, 2000b).

2002) in departure of interactions among the drainage area, the floodplain and the river. In this table, several variables are defined in order to guide scientists and water practitioners during the analysis of basic data on field.

In this way, the Table 6 also points out an example of using the Table 5 through an interaction matrix between parameters, as rows, and indicators through columns for urban biodiversity responses to environmental stimuli

**Table 4.** Urban water security management using principles, policy timing, costs and actions for challenging urban biodiversity risk (adapted from Mendiondo, 2005).

| Statutory principle | Policy timing | Cost (US$ in $hab^{-1}.m^{-2}$) | | | | Action derived |
|---|---|---|---|---|---|---|
| | | Min. | Max. | Median | Total | |
| Water risk preparedness | "before" | 1 | 5 | 2 | 2 | Early warning: nowcasting and scenario development |
| Water disaster management | "during" | 5 | 15 | 9 | 9 | Protection: Contingency Plans and Alert Systems |
| Infrastructure and logistics | "after" | 10 | 35 | 19 | 57 | Rehabilitation: Restoration, |
| Safe water control | "after" | 25 | 60 | 39 | | Recovery, Reconstruction |

**Table 5.** Ecohydrological categories for sustainable management of urban biodiversity and to reduce eutrophication at lowlands (adapted from Almeida-Neto and Mendiondo, 2008)

| Category | Continuity | Diversity | Dynamics | Resilience | Vunerability |
|---|---|---|---|---|---|
| Interaction | Drainage area ↔ river | Drainage area ↔ river | Drainage area ↔ floodplain | Floodplain ↔ river | Floodplain ↔ river |
| Indicator [Definition] | Indicator associated to number and extension of drainage network and frequency of floodplain inundations, regarded to river perenization and integration processes between surface and ground-waters and auto-depuration at macro-scale. | Quantification of permanently-flooded areas with respect to potential flood areas, as an indicator of proportion of internal lentic systems which potentially exchange nutrients, energy and information with the main river channel. | Non-linear mechanisms of multivariate processes of nutrients, of information and of energy transferred under either limnophase or potamophase stages. | Potential recovery capacity to attain a new system equilibrium under inputs of matter, energy and information | Risk analysis and management of flood prone areas with factors of: hazard (return period), vulnerability (indirect costs of loss or excess of ecosystem service) and exposition (relative location inside flooplain to main river channel). |
| Variable [dimension] | X1: number of draining sub-basins per unit of main river channel length [No./km]<br>X2: density of drainage streams per unit area [km/km²]<br>X3: frequency of occurrence of complete inundation of flooplain [No./decades]<br>X4: fraction of permanent, shallow water pools inside floodplain [km/km², %]<br>X5: relation of potential wetted perimeter of maximum floodplain cross-section and river channel wetted perimeter [m/m, %] | X6: quotient of instantaneous flooded areas, with regard to total floodplain area [km²/km², %]<br>X7: fraction of total floodplain area and upslope drainage basin area [km²/km², %]<br>X8: number of different land-uses per unit of floodplain area [No/km²] | X9: quotient of maintenance time of flooded areas after the occurrence of maximum discharge and the duration of flood pulse [min./min., %]<br>X10: fraction of inundation duration above bankfull water level and total flood pulse [min./min., %] | X11: time rate of the difference of primary production, between preserved and degraded areas at floodplain, [g Biomass/hours]<br>X12: time rate of river flow per water level (i) before, and (ii) after flooding [m³/s/m]<br>X13: dimensional surface of loops of primary production indicator versus total water level<br>X14: dimensional surface of loops of primary production indicator versus water levels above inundation floodplain terrace | X15: difference of primary production 'during' and 'after' maximum water inundation, in relation with primary production 'before' inundation [g/g, %]<br>X16: changes of permanency flows of Q5% and Q95%, from urban impacts [m³/s]<br>X17: change of probability values of 95%, from urban impacts [Probability],<br>X18: multiplication of mean velocity times water level height [m²/s] |

**Table 6.** An example of interaction matrix between parameters (rows) and indicators (columns) for urban biodiversity responses to environmental stimuli during flood pulses (defined in Table 5). Arrow direction points towards biodiversity increase.

| Parameter (dimensions) | Category and indicators | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Continuity | | | | | Diversity | | | Dynamics | | Resilience | | | | Vulnerability | | | |
| | X1↑ | X2↑ | X3↑ | X4↑ | X5↑ | X6↑ | X7↑ | X8↓ | X9↑ | X10↕ | X11↑ | X12↕ | X13↕ | X14↕ | X15↕ | X16↓ | X17↓ | X18↓ |
| Q95% | + + | + + | ? | + | + | + + | + | ? | + + | – – | + + | w/r | ? | ? | ? | – | – – | – |
| Q50% | + | + | ? | +/– | +/– | + | + | ? | + | – | + | w/r | +/– | ? | ? | +/– | ? | +/– |
| Q05% | +/– | + | + + | +/– | – | +/– | – | +/– | +/– | + | +/– | +;– | +/– | +/– | – | +/– | ? | + |
| Q01% | +/– | +/– | + | – | – – | – | – – | +/– | – | + + | – | ++;– – | – | – | – – | + | + | + + |
| EC (µS.cm$^{-1}$) | – | – | – | +/– | +/– | +/– | – | + + | +/– | +/– | – | – ; + | – | – | – | – | + | – |
| DOC (mg.L$^{-1}$) | – | – | – | +/– | – | – | – | + | – | +/– | ? | – ; ? | – | – | ? | – | + | – |
| BOD (mg.L$^{-1}$) | – | – | – | +/– | +/– | +/– | – | + | +/– | +/– | – | – ; + | – | – | – | – | + | – |
| N-tot (mg.L$^{-1}$) | +/– | + | – | +/– | + | +/– | +/– | + | + | – | + | + ; – | ? | ? | ? | + | + + | +/– |
| P-tot (mg.L$^{-1}$) | + | +/– | – | +/– | + | +/– | +/– | + | + | – | +/– | + ; – | ? | ? | ? | + + | + + | +/– |
| Biomass(gm$^{-2}$) | +/– | +/– | – | + | + | +/– | + | +/– | + | – | + | + ; + | + | +/– | – | – – | – | – |
| ISS (mg.L$^{-1}$) | + | + | + | – | – | + | – | + | – | + | – | + ; + | ? | ? | ? | + | + + | + |
| OSS(mg.L$^{-1}$) | + | + | + | +/– | – | – | – | + | – | + | – | + ; + | +/– | ? | + | + | + | ? |
| TSS(mg.L$^{-1}$) | + | + | + | – | – – | +/– | – – | + + | – – | + + | – – | + ; + | +/– | ? | ? | + + | + + | + |

Notation: Q95%: river flow discharge of expected permanency of 95% of annual river regime duration; EC: electric conductivity; DOC : dissolved organic carbon; BOD: biological organic demand; N–tot: total nitrogen; P–tot: total phosphorous; ISS: inorganic suspended solids; OSS: organic suspended solids; TSS: total suspended solids.
Biodiversity responses to environmental stimuli '↑: increase', ' ↓: decrease' , ' ↕: dual response'; Interactions expected: ' + : positive, '+ +: high positive' , ' – : negative, '– – : highly negative' , ' +/– : mixture' ,' x ; x : rising limb , recession of flooding', '? : indeterminate', 'w/r': without relation

during flood pulses. In the Table 6 the arrow direction points towards biodiversity increase, having three potential biodiversity responses to environmental stimuli: increase, decrease, and dual response.

## 4. Ecohydrological Dynamics at the Urban Flood Prone Areas

Some authors point ecological categories of flood pulses for biodiversity at floodplain (i.e. Ahearn et al., 2006; Bayley, 1996; Almeida-Neto, 2007; Almeida-Neto and Mendiondo, 2008). The challenging ecohydrological integration hot-spot for peri-urban riparian biodiversity showed in Figure 4 (Almeida-Neto and Mendiondo, 2008) point the buffering effect of loads during a passage of flood pulse and their behaviours at three different habitats of local biodiversity. Evidences and correlation between productivity and flood pulses are studied by Junk et al. (1989), Bayley (1996), Neiff (1996), Neiff et al. (2000), Ahearn et al. (2006) and Thomaz et al. (2007). The upper ordinate of Figure 4 is the average electric conductivity ($\mu S.cm^{-1}$) observed at river flow; the bottom ordinate is the main discharge at the wetted cross section of the river ($m^3.s^{-1}$); right abscissa is the water level (m); the left abscissa is the inundated area at the floodplain. In this figure, the blank areas represent lotic environment, affecting primary habitats featured as "lotic surface", "lotic", and "lotic erosional", respectively as "LoS", "Lo" and "LoE" of Table 7. This first level barely has a direct connection to the floodplain. The light grey areas of Figure 4 are the transitional connection between the main channel and the flooplain during rising limb and/or recession of flood pulse (see also Table 7). This interface region has consequences to specific habitats of "lotic depositional" (LoD), and "lotic margin" (LoM). The dark grey areas outline a complete occupance of the floodplain by waters during the flood passage which provoke impacts on biodiversity at habitats which are " lentic" (Le), " lentic depositional" (LeD), "lentic erosional" (LeE), and "lentic surface" (LeS) (see also Table 7). These different habitats are very dynamic and vary in accordance with the stream order of the river and the hierarchy of incremental areas of the basin.

## 5. Impacts on Urban Riparian Biota

To identify river channel habitat units, some methods recall studies on either macroinverstebrate or invertebrate species Ogbeibu et al 1989; 2002. The former could be addressed to aplication of the functional habitats concept to a unpolluted river (see Buffagni et al., 2000). The others rely on some toxicity thresholds and dose tolerance to assist pollution indirectly. In the Table 7, some aquatic invertebrates for different toxicity thresholds are outlined from the urban micro-catchment of *Tijuco Preto* Creek with high water pollution and biodiversity loss. In this area, toxicity evidences were previously tested with *Daphnia similis* Claus, 1876, *Ceriodaphnia silvestrii* Daday, 1902 and *Ceriodaphnia dubia* Richard, 1894 (FIPAI/PMSC, 2005). It also appears the primary feeding group of invertebrates discriminated as collector/gatherer, collector/

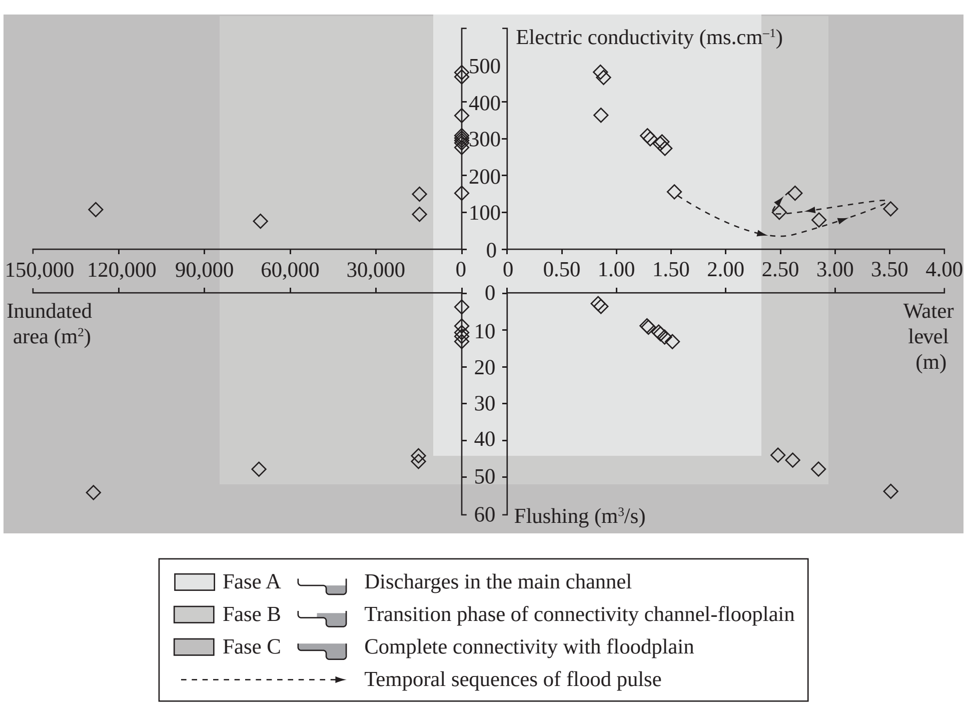


**Figure 4.** Multidimensional chart composed by water quality index (upper ordinate), water level (right abscissa), river flow (bottom ordinate) and flooded area (left abscissa). The fifth dimension is perpendicular to the forementioned axes and is composed by the permanency curve. Source: Almeida-Neto and Mendiondo (2008).

**Table 7.** Aquatic invertebrates at urban micro-catchment of *Tijuco Preto* (2 $km^2$) with high water pollution and biodiversity loss, and with toxicity evidences tested with *Daphnia similis*, *Ceriodaphnia silvestrii* and *Ceriodaphnia dubia*. Adapted from FIPAI/PMSC (2004).

| Taxa | Common name | PFG | TolV* | Habitat |
|---|---|---|---|---|
| *Platyhelminthes*, *Turbellaria* | flatworms | CG | 4 | Lo; Le |
| *Nematoda* | roundworms | PA; PI; SA | 5 | Lo; Le |
| *Annelida*, *Oligochaeta* | aquatic earthworms | CG | 8 | LeD; LoD |
| *Mollusca*, *Gastropoda* | snails and limpets | SC | 7 | Le; Lo |
| *Hemiptera*, *Naucoridae* | creeping water bugs | PR | 5 | LoD |
| *Hemiptera*, *Gerridae* | water striders | PR | U | LeS; LoS |
| *Hemiptera*, *Belostomatidae* | giant water bugs | PR | 10 | LoD |
| *Odonata*, *Zygoptera* | winged damselflies | PR | 5-9 | LoD; Le; Lo |
| *Odonata*, *Libellulidae* | skimmer dragonflies | PR | 9 | LeL |
| *Odonata*, *Aeshnidae* | darner dragonflies | PR | 3 | Le; Lo |
| *Diptera*, *Culicidae* | mosquitoes | CF | 8 | Le; LoD |
| *Diptera*, *Chironomus riparius* | midge | CG | 6-8 | Le |
| *Diptera*, *Corynoneura* sp. | non-biting midge | CG | 6-8 | Le |
| *Coleoptera*, *Hydrophilidae* | water scavenger beetles | L:PR; A:CG | 5 | Le; LoD |
| *Coleoptera* (order), *Gyrinidae* | whirligig beetles | PR | 4 | LoD; LoS; LeS |

**PFG (primary feeding group):** CG = Collector / Gatherer, CF = Collector/Filterer, SC = Scraper, SH = Shredder, PR = Predator, PA = Parasite.
**Primary habitat (potential):** Lo = Lotic, LoE = Lotic Erosional, LoD = Lotic Depositional, LoM = Lotic Margin, LoS = Lotic Surface, Le = Lentic, LeD = Lentic Depositional, LeE = Lentic Erosional, LeS=Lentic Surface.
**Other abbreviations:** A = Adult, L = Larva, TolV* = Tolerance Value (0 = min., 10 = max.), U = Undetermined.

filterer, scraper, shredder, predator, or parasite. Some authors (i.e. Nijboer et al., 2004, Arimoro et al. (2007; see discussions of Bleeker et al., 2007) have studied the diversity and distribution of *Annelida* and *Diptera* related to water quality index. The results of Tijuco Project, especially with *Chironomus riparius* Meigen, 1804 (Diptera: Chironomidae) show effects of resistant doses. Thus indirect pollution could properly be addressed though an incremental area process, or a nested catchment experiment, called as "NCE" (Mendiondo et al., 2007) in order to take account of advantages and limitations to study biodiversity at urban catchment scales. The upper part of the Figure 5 shows water quality parameters of river channel observed during the dry-season flowing from upstream (left side of figure) to downstream (right side) direction, expressed in terms of loads (left ordinates, blank symbols with lines) of biological oxygen demand (BOD), total nitrogen (N), total phosphorous (P) and total coliforms. At the bottom of Figure 5, the occurrence of aquatic invertebrates through the nested catchment experiment at this urban basin is depicted, from upstream (left) to downstream (right) direction. Those loads are compared with biodiversity indexes of the same figure (upper part, at the right ordinates, with bold lines). This figure outlines three sequential habitats: heavy loss of upstream biodiversity (from 0.1 to 0.5 $km^2$), quasi-equilibrium and transitional region (0.5 to 1.1 $km^2$) and downstream recovery (>1.1 $km^2$). Point pollution inputs from margin tributaries are depicted with dark colour symbols outlining water quality parameters from lateral, adjacent springs. Other studies (i.e. Branco et al., 2002; Strand and Assmund, 2003; Coelho et al., 2006; Vogt et al., 2007) propose fauna identification and, sometimes, with using sublethal concentrations of *Tributyltin* (TBT) and invoke biomanipulation (e.g. Crisman and Beaver, 1990; Hansson et al., 1998; Gomez-Ariza et al. (1999) to evaluate tolerance dose of biota in order to assist ecotoxicology explanation of urban and peri-urban pollution into riparian systems Pascoe et al (1989).

## 6. Urban Flow Regimes – Are Ecological Constraints Well Indicated into Policy Scenarios?

The adaptation of biota of Figure 5 to urban riparian areas depends upon the flow regimes and the manner of how this adaptation cope with high and low flows (Brookes, 1995; Petts (1990); Petts et al (1989)). High flows are important to permit bankfull effects of geomorphology conditions of terraces and sediments to form natural benches, pools and riffles for the habitat of benthos, plancton and fishes. The Figure 6 presents a high-flow analysis through maximum flood specific discharges at incremental areas, through NCE approach, of urban micro-catchment of *Tijuco Preto* Creek and comparing restoration scenarios and no planning conditions, with emphasis in regulating, cultural and supporting environmental services (see also Table 7, Figure 5 and Figure 6). The difference between scenarios for years 2000, 2010 or 2015 and the previous condition, for year 1960, show up the negative impact in terms of regulating services. For example, for the situation in year 2000, upland areas

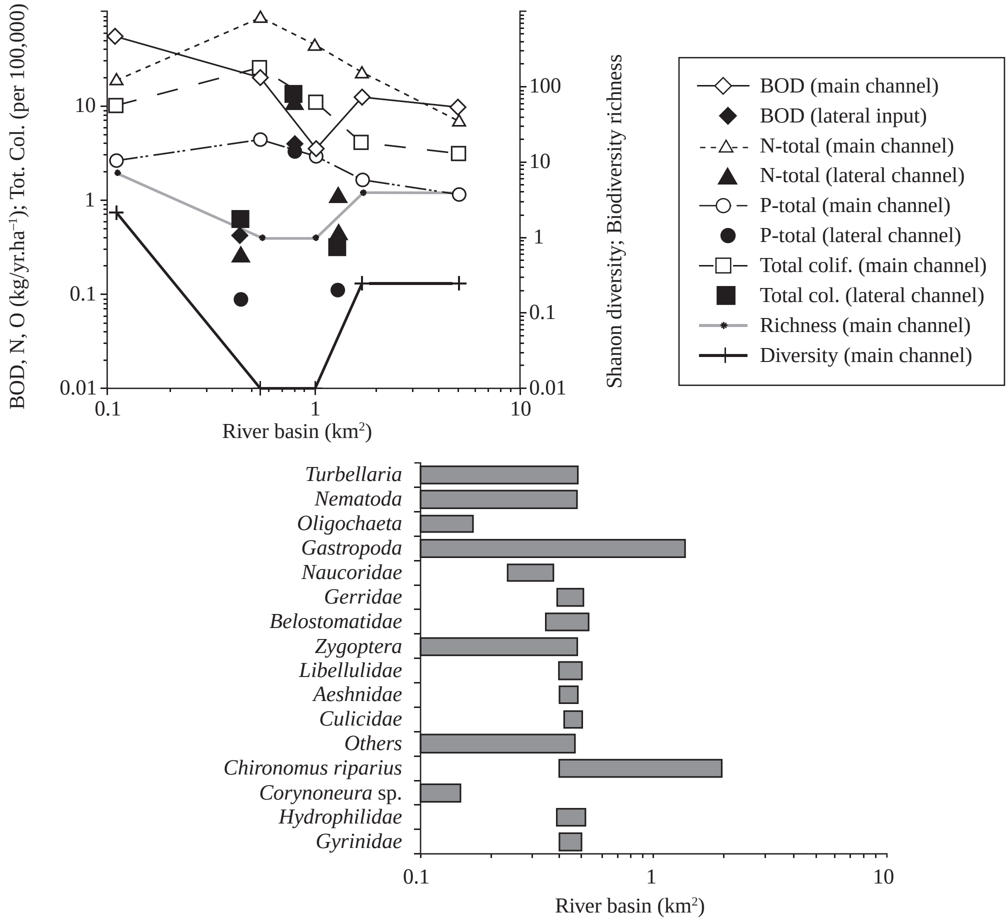


**Figure 5.** Upper picture: Dry-season loads of water quality parameters of main river channel (left ordinates, blank symbols with lines) and compared with biodiversity indexes (right ordinates, with bold lines) through a nested catchment experiment of urban basin, flowing from upstream (left side ) to downstream (right side) direction. Bottom picture: Occurrence of aquatic invertebrates from upstream (left) to downstream (right) direction. Source: FIPAI/PMSC (2005).

with high biodiversity loss and decline of cultural services (<0.5 km$^2$, see Figure 6) also provoke downstream impacts of increasing specific discharges at downstream areas (>0.5 km$^2$). On the one hand, some future restoration scenarios (until 2015), however, cannot mitigate per se all flow discharges increase because some prelicenced, but not yet built up urbanization quarters at the 0.5 km$^2$ area, would be fully implemented in accordance to market prices of dwelling lots and profit speculation. On the other hand, some extra environmental services are needed at the 1 km$^2$ scale area in terms of multiple use detention basin to mitigate destructive flows.

Complementary to floods, the low-flow analysis of scenarios of at peri-urban river basin (Figure 7) is addressed comparing the duration of permanency (abscissa axis), average chlorophyll balance of productivity-to-respiration rate (right ordinates) and specific discharges (left ordinates). This chart is adequate to every size of river basin, if NCE approach is applied, and could be used to make inferences about the sources of loads, either autochtonous or allochtonous of the river. Indirectly, it also could be envisaged towards linking minimum flow needs of urban and peri-urban rivers to maintain various equally possible states of in-stream biodiversity. In this figure, left ordinates, with solid lines, depict the specific discharge of permanency curve with excedance probability in the abscissae. Right ordinates outline different scenarios of chlorophyll-*a* in correspondence with the same probability values. The first scenario, with bold dotted lines, is related to chlorophyll-*a* productivity higher than respiration (P/R > 1) derived from the mixing process of fitobenthos and alloctonous loads incorporated into the main flux of the river and during flood passages (potamophase; see Bottino, 2008). Conversely, during medium to low flows, the second scenario (with double continuous line) shows a quasi steady-state, or quasi "lentic equilibrium", without connection of the main river with adjacent floodplain. In this second scenario of Figure 7, the net flux of chlorophyll-*a* remains constant (≈ 0.05 mg.s$^{-1}$.km$^{-2}$) between 25% to 90% of permanency curve that corresponds to specific discharges ranging from 15 to 5 L s$^{-1}$.km$^{-2}$). For this scenario, a decrease of net chlorophyll-*a* flux is expected for discharges expected to occur for lower than $Q_{90\%}$, because of possible anoxic conditions and low radiation inputs. When lentic behavior is persist-

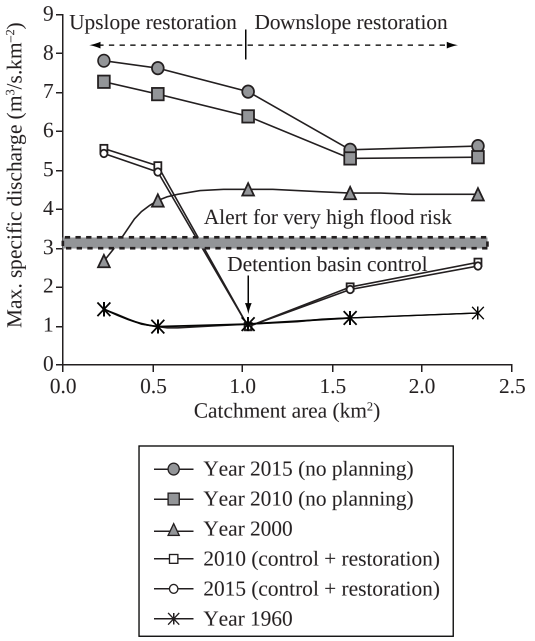


**Figure 6.** High flood analysis from maximum flood specific discharges at urban basin of Tijuco Preto Creek with comparing biodiversity restoration scenarios and no planning conditions, with emphasis in regulating, cultural and supporting environmental services (see Table 3 and Figure 5).

ent in time, without floodplain connections to river channel, a general drop of chlorophyll-*a* net flux is expected for a new, third scenario (with double, non-continuous line). This novel situation is characterized by a moderate reduction of the P/R ratio but with high photosynthesis rates yet. However, if this situation persists with low photosynthesis rates, the P/R ratio would maintain values below previous ones and consuming some autoctonous organic matter, as showed in the fourth scenario of Figure 7. The forementioned scenarios thereby confirm several minimum flows are possible to various levels of organic matter production and with a wide range of possibilities for riparian biodiversity to evolute from them. In short, several combinations of net productivity could attend dynamical, ecological conditions of river flows, especially depending upon water quality.

## 7. Water Quality Chart for Restoration Schemes – Towards Healthier Urban Rivers?

The Water Quality Structure Chart (Petts and Calow, 1996; DVWK, 1996; Riley, 1998; Mendiondo, 2000a, 2000b) of urban rivers with biodiversity to be restored is one alternative to be proposed through six elements, explained as follows: 1) water-course evolution, 2) longitudinal profile, 3) bed substrate, 4) cross-section profile, 5) margin structure, 6) adjacent area to water-course. First, the water course evolution is related to own river's curvature, bend erosion, longitudinal benches, and specific water-course structure. Second, the longitudinal profile of urban river is analyzed through potential cross buildings, existence of natural or artificial pipe networks, what type of backwater effects, cross benches, stream variation and stream diversity. Third, the bed structure is depicted with the bed constitution, substrate diversity and specific bed structures, most significant for fito- and zoo-benthos. Fourth, the cross-section profile can be studied with the profile type, depth, width from erosion and its natural variation and hydraulic conveyance. The fifth element (margin structure) is related to vegetation and artificial construction. Finally, the adjacent area to water-course is regarded to land use, riparian marginal strips and, when high urbanization is evident, what kind of deteriorated floodplain structure exists.

In spite of the water quality structure chart, alternative land use, riparian strips and floodplain structure appear. Typical land-use are composed by ground-fixed forest, typical floodplain biotope, fallow, ploughed area, grassland, prairie, no-fixed forest, farm, garden, development with or without free-areas, and deteriorated floodplain structure. The riparian marginal strips at urban environments are usually composed by mixed, open forest or succession, riparian vegetation strip, edged man-made strip, or without riparian strip due to land-use. The deteriorated urban floodplain structures are excavation sites, traffic ways, trash deposit, flood protection construction and water-incompatible construction. Restoration projects also could derive the effects of pronounced terrace border, natural shore-wall, flood-inundation canal, springs, old arm, "bayou", paleo-channel, ponds, and, when possible, include fish pond in adjacent area. These methods aid to envisage toward the assessment of 'ecological integrity' in running waters using surface flow types and habitat structure (Harper et al., 2000).

## 8. Biodiversity Restoration Objectives – How Do Tradeoffs Emerge from Lessons Learnt?

Objectives for biodiversity enhancement in urban areas give direction to the general approach, design, and implementation of the restoration effort. Thus, biodiversity restoration objectives should support the goals and also go directly from problem/opportunity identification and analysis. Restoration objectives should be defined in terms of the same conditions identified in the problem analysis and should specifically state which impaired stream corridor condition(s) will be moved toward which particular reference level or desired condition(s). The reference conditions provide an approach to measure the success of the restoration effort; restoration objectives should therefore identify both impaired stream corridor conditions and a quantitative measure of what constitutes unimpaired (restored) conditions. Restoration objectives expressed in terms of measurable stream corridor conditions provide the basis for monitoring the success of the project in meeting condition biodiversity goals for the stream corridor. As in the case of restoration goals, it is imperative that restoration objectives be realistic and

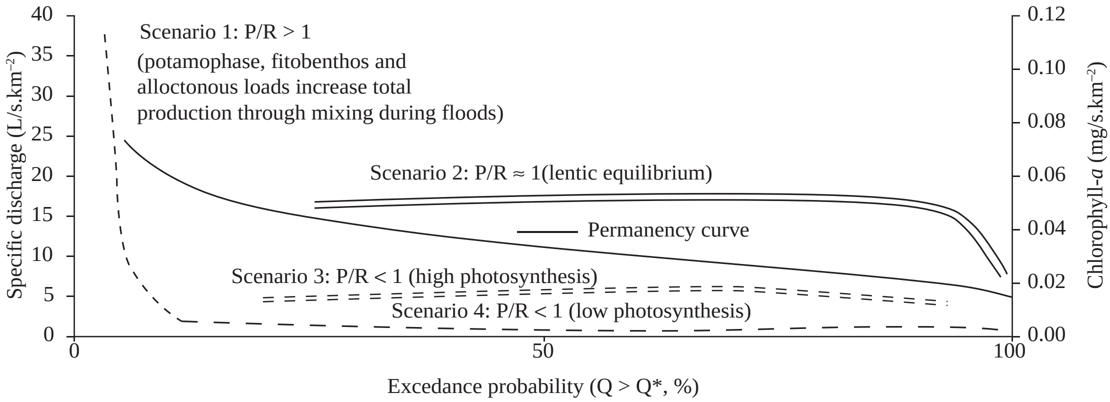


**Figure 7.** Low flow analysis of scenarios of at peri-urban river basin, comparing discharge permanency (abscissa axis), scenarios of average chlorophyll-*a* balance of productivity-to-respiration rate (right ordinates) and specific discharges (left ordinates).

measurable. Thus, objectives must therefore be "based on the site's expected capability, its feasible carrying capacity and system's resiliency, as a whole, and not necessarily on its unaltered natural potential" (Mendiondo, 1999; Mendiondo, 2000a, 2000b). It is much more useful to have realistic objectives reflecting river corridor conditions that are both achievable and measurable than to have vague, idealistic objectives reflecting conditions that are neither. Available guidelines (i.e. DVWK, 1996; FISCWG 1998; Mendiondo, 1999) are rather similar in river restoration features, and could be worked for the potential and feasible goal [in German restoration projects, worldwide known, is the guiding image or "Leitbild"]. Alternative concepts, through measures and scenarios (see Table 8) aid to attain the ecological development. To approach biodiversity restoration goals, either ideal or feasible pointed in Table 8, some concepts should be included as ecological value, tolerance, susceptibly, responsiveness and self-sustainability (Mendiondo, 2000a). Biodiversity values are associated with a change from one set of conditions to another. Often, they are not economic values, but rather amenity values such as improved water quality, improved habitat for native aquatic or riparian species, or improved recreational experiences. Tolerance concept addresses acceptable levels of change in conditions in the river corridor at two levels: 1) variable "management" tolerance, responsive to social concerns for selected areas, and 2) absolute "resource" tolerance, that is the minimal acceptable permanent damage for river corridors in need of restoration that usually (but not always) exceed these tolerance limits Denslow, 1985.

## 9. Adapting to Change – How do Stakeholders Should Manage Costs for Capacity Building?

Previous comments are envisaged to assimilate with stakeholders and inhabitants the fostering solutions proposed, the costs of the project during its lifetime and the capacity building of dweller to empower key projects into long-term sociocultural customs or incorporated traditions at the urban society. For example, Figure 8 shows previous (left side) and planned (right side) restoration guiding image and measures to enhance environmental cultural services of local biodiversity of the retention basin projected at urban scale of 1 $km^2$ (see Figure 6). Consequently, Figure 9, from FINEP-CT-Hidro 01.02.0086.00 (2008), shows the time evolution of costs as an equivalent measure of environmental services of the biodiversity restoration project of urban basin, in the short-term (◊), in the medium-term (■) and at long-term (▲), respectively for +2 years, +5 years, and +10 years after restoration works begin. The ordinate of Figure 9 is the total costs, investment plus operation and maintenance, divided by total number of inhabitants living at the respective nested drainage area of river basin indicated at abscissa axis. Total specific cost of biodiversity restoration project is calculated in ca. US$ 2.5 million $km^{-2}$ of drainage area of river basin (FIPAI-PMSC, 2005). Comparing with the Gross Net Product of the own Municipality, the average amount of environmental services of this urban basin are estimated in a range from 28 to 33 million US$ $km^{-2}$. This figures point that river restoration projects for biodiversity enhancement is a small amount in comparison with the benefits that urban biodiversity offers at most at an urban basin. Project costs vary in a wide range in dependence with the efficiency, the methods used and the usage to evaluate costs per unit drainage area or per river's unit length. Enhancement and rehabilitation costs differ from restoration or renaturalization ones (Mendiondo, 1999). Enhancement-biodiversity projects cost ca. 3 U$ million $km^{-1}$ of river length and 1.5 $km^{-2}$ of drainage basin. Conversely, restoration projects rise to 25 U$ million $km^{-1}$ of river, and renaturalization can rise to more

**Figure 8.** Previous (left) and planned (right) restoration measures to enhance environmental services and biodiversity at urban scale of 1 km$^2$ (see Figure 5 and Figure 6).

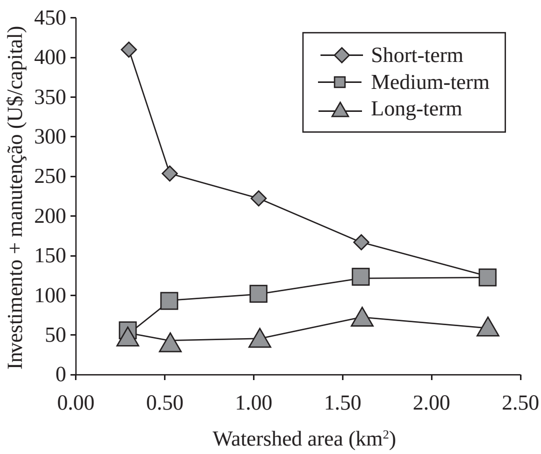


**Figure 9.** Total costs of urban river restoration project in the short-term (+2 years after construction, ◊), in the medium-term (+5 years, ■) and at long-term (+10 years, ▲).

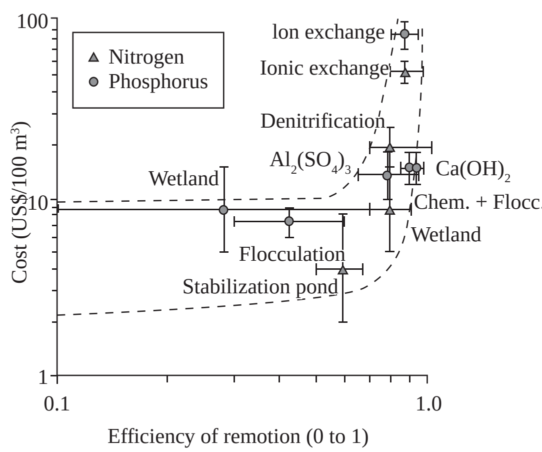


**Figure 10.** Estimated costs and efficiencies of eutrophication removal in water treatment for household. Adapted from several authors.

**Table 8.** Example of project management from alternative measures (from "A" to "E") to integrated scenarios (1 to 7) of urban biodiversity restoration with recovery of urban flood-dikes proposed to enhance aquatic, amphibian and riparian biotopes (Mendiondo, 2000b).

| Option | Characteristics of measures and scenarios |
|---|---|
| **Individual ecologically-based measures for flood mitigation from potential goal (ideal goal)** | |
| A | Widening of river cross-sections and recovery of bank reinforcement |
| B | Recovery of river embankment and establishment of riparian strips |
| C | Reactivation of bifurcation channels, old tributaries and ancient bows |
| D | Recovery of flood-dikes, closing of drainage ditches |
| E | Initiation of flood-plain vegetation |
| **Integrated scenarios of urban biodiversity restoration (feasible goal )** | |
| 1 | Dike-recovery through maintaining land-use and position of farm and grasslands |
| 2 | Dike-recovery, but with spatial removal of existing areas (grass-areas at the front-side, farm-areas behind of dike; farm/grass ratio unchanged) |
| 3 | Dike-recovery, farm conversion into grassland, creation of a riparian margin (10 m) with natural succession, with the design of infiltration-recharge strips. |
| 4 | as Scenario 3, with increasing of grasslands |
| 5 | as Scenario 4, with closing drainage ditches. |
| 6 | as scenario 5, with reactivation of relics at ancient river bows (i.e. paleochannels), |
| 7 | Dike restoration, arrangement and regeneration of floodplain-vegetation. |

than 90 U\$ million km$^{-1}$ of river (Mendiondo, 2006). All these costs support investment and maintenance during the half life of the project to increase functions at floodplain ecotones. These costs should be fully compared with costs and efficiencies of water treatment of eutrophication removal (Figure 10).

## 10. Pilot Demonstrative Projects – How do We Support Flexible Water Governance?

Looking at Figure 9, the higher river drainage area, the lower specific costs per capita. This outlines the needs for hydrosolidarity trade-offs through implementing river basin association to compensate strong biodiversity degradation at upland areas with societal management capacity at lowlands. Figure 11 presents the first *Tijuco Preto* Basin Association as a way of introducing an adaptive management with community participation to recover urban biodiversity of Tijuco Preto creek. In the short-term scenario, in process since year 2005 to present, the stakeholders have been introduced to the problem (left-upper picture), addressed a river basin association declaration based upon hydrosolidarity principles (right-upper picture), which encourage the beginning of engineering earth-works (left-bottom picture) and setting up a new renaturalization channel project with bioengineering techniques to enhance biodiversity conservation of upland areas (right, bottom picture). This example is a demonstrative pilot project which could be better derived and replicated for other multipurpose schemes in metropolitan regions, as Sao Paulo mega-city, under decentralization management of urban districts. For example, Table 9 shows a potential example of a feasible demonstrative pilot project to restore urban biodiversity at adjacent areas and tributaries to urban strategic reservoirs and with a kick-off in year 2008. The final line of Table 9 depicts interval of costs of each phase expressed as percentage from total project budget (Mendiondo and Tundisi, 2007). It is worth noting that costs and efficiencies could vary, but are intermediate between enhancement and rehabilitation projects (see Table 4). Furthermore, some parts of complex demonstrative pilot projects can be sustained through full-scale experiments for education purposes of river science (Wilcox et al., 2008). These full-scale experiments help to refine forecasts of response of streambed composition, stream morphology, nutrient flux, and biotic community to changes in water and sediment supply, or to engineered channel designs to mitigate against urban water-borne vectors, i.e. *Aedes aegypti* (Linnaeus, 1762).

Finally, pilot demonstrative projects could be well adapted to official river basin committees which mas-


**Figure 11.** Adaptive management with community participation to recover urban biodiversity of Tijuco Preto creek until 2005, introducing stakeholders' motivation (left-upper picture), addressing river basin association declaration based upon hydrosolidarity principles (right-upper picture), beginning engineering earth-works (left-bottom picture) and setting new channel project with bioengineering techniques (right, bottom picture). Source FINEP-CT-Hidro 01.02.0086.00 (2008).

**Table 9.** Example of a demonstrative pilot project to restore urban biodiversity at adjacent areas and tributaries to an urban reservoir. Last line of the table depicts interval of costs of each phase related to total project budget. Kick-off year: 2008.

| **1.** | **2.** | **3.** | **4.** | **5.** | **6.** |
|---|---|---|---|---|---|
| Concept Paper and Kick-off Policy Workshop | Lifetime of Reservoir and Basins through Technical Assessment on Water Security | Value of Ecosystem Services | Emergency Actions and Short-term Mitigation Strategies | Policy Workshop and Feedback Dialogue on Water Security Goals | TORs: Terms of Reference on Security and Eutrophication of 'Water for Life' |
| (1.1)<br>Publishing the Whole Strategy in a Participative Workshop with Stakeholders and Decision-makers<br><br>(1.2)<br>Introduction for "Water Security for Life";<br>Motivation; Problems;<br>Lessons Learned;<br>Stakeholders;<br>Goals<br><br>(1.3)<br>Reflection:<br>Goals of "Water for Life: 2010, 2020, 2030, 2050, 2100", Actions;<br>Challenges; Chances;<br>Testimonies<br><br>(1.4)<br>Tutorial for next phases | (2.1)<br>In situ diagnosis of social, economical, physical, biological chemical, cultural and institutional variables.<br><br>(2.2)<br>Integrated Models of:<br>society,<br>ecology,<br>sedimentlogy,<br>economics (insurance),<br>global change,<br>hydrology<br><br>(2.3)<br>Scenarios: institutional, environmental arrangements and water security feasible at the long-term (2010 – 2100) | (3.1)<br>Water Security with Value of Ecosystem Services of:<br>Supporting<br>Provision;<br>Regulation;<br>Cultural<br><br>(3.2)<br>Permission of Services for Security,<br>Life; Health; Social; Human Well-Being<br><br>(3.3)<br>Willingness to Pay and Prices of Services for:<br>Conflict Resolution and Trade-offs | (4.1)<br>Structural Measures: eco-technology and eco-hydrology towards Ecosystem Services Valorization<br><br>(4.2)<br>Non-Structural Measures for Maintaining Services until year 2010:<br>Tax Incentives;<br>Insurances;<br>Monitoring;<br>Early Warning;<br>River Association;<br>Public-Private Partnerships;<br>Education and Training<br><br>(4.3)<br>Protocol of Institutional Empowerment, Governance, Policies and Adaptive Management until 2010. | (5.1)<br>Strategic, Multi-Sector and Participative Goals "2010, 2020 e 2030"<br><br>(5.2)<br>Strategic Management at the Long-Term; Integrated Goals; Identification of Stakeholder (old and new); Selection of Indicators and Variables<br><br>(5.3)<br>Implementation of Initial Policies; Assessment of Sets of Indicators; Methodology of Hierarchy of Priorities | TORs of Demonstrative Projects (scenarios, goals, and actions):<br><br>Strategic Management;<br><br>Institutional Empowerment;<br><br>Risk Mitigation and Conflict Reduction<br><br>Funding;<br><br>Incentive-driven Policies;<br><br>Social Inclusion;<br><br>Early Warning;<br><br>Sustainable Urbanization<br><br>Structural Measures |
| 2-5% | 20-40% | 10-12% | 20-35% | 4-8% | 8-10% |

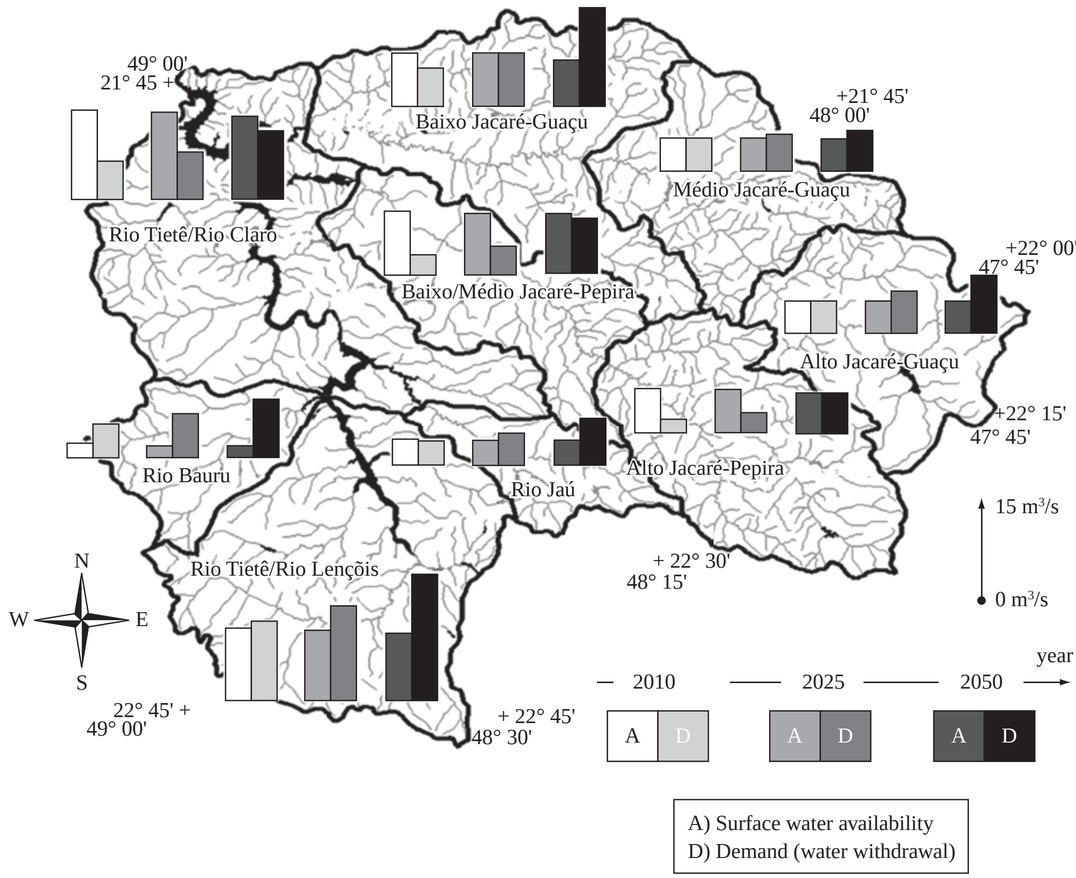


**Figure 12.** Impacts of urban biodiversity should be related to water availability and to multi-sector water withdrawal for the period of 2010 and 2050 at river basins of Tiete Jacare River Basin (11,400 km$^2$) at Sao Paulo State, Brazil (Mendiondo and Macedo, 2007).

ter plans until year 2050 are foresighted. In this case, Figure 12 point the water availability and sector water demands for nine sub-basins of Tiete-Jacaré River Basin (ca. 11,400 Km$^2$, Mendiondo and Macedo, 2007). All these scenarios are assessed in terms of different regional climate change which will affect permanency curves of rivers and water-sector demands, i.e. irrigation, industry, household, livestock, autodepuration, either for a cash-crop scenario, e.g. “ethanol boom market”, or alternative agropole approaches.

## 11. Outlook – Where Look Forward to Promising Innovation Topics of Research?

The previous sections addressed some challenges and options to underpin scientific approaches of urban biodiversity in terms of ecohydrological opportunities. Some milestones are further recommended to guide future works in order to evaluate a cross-cutting integration with stakeholders and community-based alliances to preserve urban riparian areas, as follows:

- First, the highlights to approach the urban basin as the baseline unit need to assess input yield into the river environment, i.e. though mass fluxes and loads per time per unit drainage area, as nutrient yields, to capture relevant spatiotemporal variables.
- That previous condition is optimally related to a further postulate of multidimensional analysis of possible hyper-states that merge loadings, fluxes and riparian web storage, i.e. a five dimensional axis composed by biodiversity parameter, inundation area, river flow, water level and the probability of discharge permanency.
- Third, when the fore-mentioned multidimensional analysis is performed, the hydrological regimes could be better linked to ecological flows approaching to river biodiversity, either at exploratory study or scenario condition, i.e. with P/R ratio derived from and coupled with annual permanency of river flows according to intra-annual seasonality or land-use changes at urban or peri-urban areas.
- When no direct measurement or experimental observation are available, it is worth using environmental modeling of water quality and biodiversity index at multiple scales as a non-

invasive method; for instance, the dynamical time-step loop of expected biomass during a flood passage should be deeply studied in terms of hypothesis testing of net web productivity of urban floodplain regardless whether it is very frequent or it could be reclaimed through restoration programs.

- Further studies can be envisaged for spatially scaling biota thresholds and carrying capacity to account some time-discrete phenomena, e.g. flood disruption effects, as well from continuous process at adjacent areas to river corridors, like non-point pollution of perched waters at vadose zone or groundwater recharges along the annual flow regime.
- From the above commentaries, one opportunity is to regionalize point measures or estimations of biodiversity, i.e. species richness, through scaling-up ecotoxicology doses as surrogate bioindicators from different urban micro-catchments upwards higher order watersheds or basins; i.e. aggregating rules of spatial indicators of invasive, dose-resistant or new species linking to the topology of river network or through nested catchment areas inside it and for different levels and types of urbanization.
- Ecosystems services of urban freshwater biodiversity should be clearly discussed with stakeholders and local communities through learning exercises, demonstrative pilot projects and educational games. For instance, subtropical headwaters that fully provide freshwater to strategic reservoirs should be frontally approached as "water footprint generators" in order to better assist water companies to overcome the overall lack of efficiency of water distribution systems and to find a common sense in terms of the payment of environmental services provided. They are crucial to compensate risks of water toxicity and water-borne diseases of urban areas, and to mitigate epidemic surges of dengue at fast growing metropolitan areas.

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