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AQUATIC ECOLOGY

MAIN PRINCIPLES ON WATER QUALITY, THE USE OF AQUATIC BIOINDICATORS AND FLUVIAL ECOLOGICAL RESTORATION IN ECUADOR

PRINCIPIOS FUNDAMENTALES EN TORNO A LA CALIDAD DEL AGUA, EL USO DE BIOINDICADORES ACUÁTICOS Y LA RESTAURACIÓN ECOLÓGICA FLUVIAL EN ECUADOR

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Abstract

This work was developed as a complement to the ecological restoration component contemplated within the framework of action of the Environmental Management Plan of FONAG (Fund for Water Conservation), an institution attached to the Municipality of Quito. The document is part of the baseline in the creation of a suitable scenario to undertake activities of rivers ecological restoration, where it is necessary. At the municipal level, it is important that the considerations discussed in this paper, as well as initiatives for river restoration, should be inserted as one of the main components within the environmental management plans that each local government (GAD) has to undertake in the territory of its jurisdiction, and it is addressed as an element that requires a permanent monitoring in order to detect the changes in the quality and quantity of water that can be presented in a given area and the corresponding management actions to be taken.
Keywords: Water quality, Ecuador, bio-indicators, rivers ecological restoration.

Resumen

El presente trabajo se desarrolló como complemento al componente de restauración ecológica contemplado dentro del marco de acción del Plan de Gestión Ambiental del FONAG (Fondo para la conservación del Agua), institución adscrita al Municipio de Quito. El documento forma parte de una línea base de información que gira en torno a la construcción de un escenario adecuado para emprender actividades de restauración ecológica fluvial, en los ambientes en los que ésta fuera necesaria. A nivel municipal es importante que las consideraciones discutidas en la presente investigación así como las iniciativas de restauración ecológica fluvial se incluyan como un componente más dentro de los planes de gestión ambiental que cada gobierno local (GAD) emprende en el territorio de su jurisdicción, y se aborde como un elemento que requiere un permanente seguimiento y monitoreo para detectar oportunamente cambios en la calidad y cantidad del agua que se puedan presentar en una determinada zona y que a la vez esto permita tomar las acciones de manejo que correspondan.

Palabras clave: calidad del agua, Ecuador, bioindicadores, restauración ecológica fluvial.

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1 Introduction

1.1 Diagnosis of the water problem in Ecuador

For many years in Ecuador, water management has focused on initiatives to improve the supply of water in quantity, not necessarily in quality. The limited availability of economic resources is usually added for the conservation of primary water sources and a management criterion at the level of the river basin as the unit of analysis. Therefore, efforts to prevent pollution and recover contaminated water bodies have been minimal, responding to particular interests (Solanes and Peña, 2003). At present, Quito does not have a sewage treatment plant, except for a few industrially focused exceptions. It is expected that by 2018, the city will have its first water treatment plant (Calles, 2012), until the main basins and microbasins that receive the contaminated water from the city discharge their waters to the Machángara, Guayllabamba and Monjas without any treatment. The latter, for example, receives the water of the different anthropogenic activities from the highlands of the Atacazo and other nearby areas.

At national level only the city of Cuenca and some sectors of Guayaquil and Loja, have sewage treatment systems, which have allowed them to reduce the rates of parasitosis, intestinal diseases of people and the loss of aquatic biodiversity due to the contamination of bodies of water near populated and/or urban centers (Lloret, 2002).

The limitations of water availability, in terms of quality, and the important national population growth are exerting a strong pressure on the high areas of the highlands from which the primary water sources originate, generating, as a consequence, the overexploitation of the resource and the deterioration of its natural vegetation cover in the recharge areas. Therefore, it is urgent to take environmental management measures to recover these primary water sources that have already been intervened, but that can be restored with an adequate management and recovery of the riverbank areas, along with the bodies of water, and a plan for the delimitation of hydrological protection zones (González and García, 2007; Magdaleno, 2011; Rodríguez Quiñónez, 2012; Ramírez López, 2015).

1.2 Reference legal framework

The Magna Carta of the Republic of Ecuador of 2008, in its chapter seven (Article 71), establishes the rights of nature as fundamental to guarantee the Good Living of people in a natural environment, healthy and free from contamination. Similarly, Article 72 of the same chapter refers to the rights that nature has to be restored in cases of intervention by human beings, as a result of their socio-economic activities. It also indicates that in the event of environmental impacts, those responsible for them are forced to take mitigating and restorative measures to return the original natural state to the disturbed environment (Asamblea Constituyente, 2008).

For the fulfillment of the indicated, the Ecuadorian State, through the highest environmental authority of the country, the Ministry of Environment (MAE), has generated a series of laws, regulations and control systems, which allow to regulate and monitor the activities generated by the human being and that attempt or could be attacking the integrity of nature and its ecosystemic functionality.

In its second chapter, the Magna Carta itself makes reference to biodiversity and natural resources. Article 395 establishes that the environmental management policies of the State must be applied by all entities of public or private origin and will be mandatory in their fulfillment. Article 400, in turn, refers to the importance of conserving the biodiversity and natural resources of any natural or legal person, declaring it as an action of public interest.

The Law on Environmental Management of Ecuador shows that the highest environmental authority (Ministerio del Ambiente, 2003), (MAE) has the sanctioning power in case of environmental damage caused by activities from the public or private sector in any field of action, as well as the attributions of granting the licensing and operating permits to these institutions.

In section two, article 47 mentions the importance of special management areas, in which FONAG has considered primary water sources (paramo streams) as part of these ecosystems due to its unique wealth species of native flora and fauna. In chapter III, article 57, reference is also made to the obligatory nature of the recovery and mitigation of areas degraded by negative environmental impacts.

The Law of Environmental Management in its articles 1-6 highlights the importance, principles and guidelines of the environmental policy that public and private institutions must promote in each of their activities. In addition, this law indicates the permissible limits, controls and sanctions in environmental matters. In accordance with this legal framework is the Law of Prevention and Control of Environmental Pollution, in which reference is made to both processes regarding air (Chapter V); the waters (chapter VI) and the soils (chapter VII), constituting the regulatory framework on which the FONAG frames its environmental management procedures.

On the other hand, the Ministerio del Ambiente (2003) (Unified Text of Secondary Legislation, Environment) is a technical norm that is covered by the Law of Environmental Management and the Regulation to the Law of Environmental Management for the Prevention and Control of Pollution Environmental and subject to the provisions of these, is mandatory and applies throughout the national territory.

This technical standard addresses or establishes:

a. The permissible limits, provisions and prohibitions for discharges in bodies of water or sewerage systems (Book VI annex I).

b. The criteria of water quality for its different uses (Book VI annex I); and

c. The methods and procedures to determine the presence of contaminants in water (Book VI Annex I).

All these rules and regulations must be taken into account for the operation and environmental management processes that the FONAG contemplates within its strategic planning.

Article 318 of the same Constitution consecrates water as a strategic national patrimony for public use; and the State, through the unique water authority SENAGUA (National Water Secretariat), created by Executive Decree 1088 of May 15, 2008, generates the proposal of the new Water Law (Asamblea Nacional, 2010), and in turn is responsible for the planning and management of water resources that will be managed under this order of priority: a. Human consumption. b. Irrigation that guarantees food sovereignty. c. Ecological flow, and d. Productive activities.

Under this context and legal structure, the management of water resources in Ecuador has attempted to regulate and manage the proper use of the resource. However, it is essential to strengthen the technical element to increase efficiency, effectiveness and operability of these initiatives (Asamblea Nacional, 2010).

2 Biological groups indicators of water quality

2.1 Macroinvertebrates as bioindicators of environmental quality

The high anthropic pressure, to which freshwater ecosystems have been exposed in Ecuador during the last twenty years, reveals the deterioration of bodies of water, both in quantity and quality. One of the most successful and economic ways to determine the level of impact and the type of contaminant or exogenous element present in a body of water is using different aquatic organisms as indicators of these changes or disturbances (González and Lozano, 2004; Escobar, Terneus and Yánez, 2013; Terneus, 2015).

A bioindicator organism is a species or group of species that have particular environmental requirements in relation to a set of physical or chemical variables; this species or these species can present changes in their presence and spatial distribution, number, morphology or behavior when the conditions of the ecological system are altered (Rosenberg and Resh, 1993). In short, these organisms occupy a habitat whose environmental requirements are adapted; any change in environmental conditions will be reflected in the structure, composition and dynamics of the aquatic macroinvertebrate communities that inhabit there (Terneus, Racines and Hernández, 2012).

Among these organisms, macroinvertebrates as bioindicators play an important role in the proper management of water resources.

Within these particular requirements it has been determined that each group or guild of aquatic macroinvertebrates shows levels of specialization or preference for occupying specific microenvironments; among these: micro rocky, muddy, litter, sand, silt or clays habitats. To this is added the preference for certain physical (hydrodynamic) aspects such as water dynamics and current flows: strong, medium or weak current zones or the presence of chemical elements (Figure 1). Therefore, the presence, abundance, absence of these organisms usually indicate the conditions of the body of water or of a sector of it.

The presence or absence of certain characteristic groups such as the ephemeroptera, plecoptera and trichoptera (on which the EPT index is based) are indicators of good water quality, and many of them occupy spaces of fast water, well oxygenated and shallow, while that the chironomid and ceratopogonid diptera and certain annelids occupy shallow, muddy and deep water, which is why they are water indicators with a high organic load. The relationship of these groups in proportion and richness provide fairly accurate information about the health status of the aquatic environment (Jacobsen, Schultz and Encalada, 1997; Giacometti and Bersosa, 2006).

Figure 1. Source of primary water in an Ecuadorian wasteland with a high iron content. Only certain species of macroinvertebrates are adapted to it.

2.2 General description and characteristics of the main groups of aquatic macroinvertebrates as bioindicators

Below, some general characteristics of the main bioindicator groups are highlighted, based on the work of Racines (2014), which demonstrates how aquatic macroinvertebrates can express the state of ecological health, based on the calculation of tolerance indices and sensitivity to contamination of water in the Ecuadorian highlands.

The aquatic oligochaetes (*Oligochaeta* class) make up one of the most important groups of invertebrates present in lakes, rivers and reservoirs. They have morphological parameters similar to that of terrestrial oligochaetes: their size varies between 1 and 30 mm. They eat filamentous algae; their breathing is cutaneous. The oligochaetes are an important link in the benthic trophic chain, mainly in eutrophized or polluted water, where they reach very high densities and serve as food for benthic fish, turbelaries, leeches, nematodes and insect larvae (Brinkhurst, 1980).

The members of this group have been defined as special bioindicators for different physical and chemical parameters, such as: substrate types, organic carbon, phosphorus and several heavy metals, generally hydrocarbon residues (Chapman, Farrell and Brinkhurst, 1982).

On the other hand, the Coleoptera order, which has the greatest diversity of species in the world, lives in continental and lentic waters, clean waters, with high oxygen concentrations and average temperatures (Roldan Perez, 1988). They have anterior wings or elytra, membranous posterior wings, biting mouth apparatus (Hickman, Roberts and Larson, 2009). The larvae of the coleopterans present very diverse forms, the abdomen presents lateral or ventral gills, they have complete metamorphosis and the adult is morphologically very different (Figure 2).

Figure 2. Coleoptera larvae of the Elmidae family. Next to its legs are the gills that allow it to breathe in aquatic environments with a high concentration of oxygen, courtesy of M.J. Racines.

The Diptera order is the most complex, abundant and best distributed on the planet. It is composed of holometabolous insects, that is, their life cycles consist of eggs, aquatic larvae, pupae and flying adults, from which the bioindicator phase is the larva. Its habitat is made up of rivers of stagnant water and current (Roldan Perez, 1996). The most important characteristics of the dipterous larvae are the absence of thoracic legs, the soft body covered with bristles, apical spines or crown of hooks in extensions that help locomotion and adhesion to the substrate (Roldan Perez, 1988).

Dipterous are considered the best indicators of the presence of a high degree of organic matter in bodies of water, their most frequent families are *Psychodidae, Tipulidae, Blephariceridae, Culicidae, Ceratopogonidae, Chironomidae, Simuliidae, Tabanidae and Muscidae* (Roldan Perez, 1996). The Chironomidae family is associated with water of abundant presence of organic matter (in lotic and lentic systems), and low concentrations of dissolved oxygen. However, within this family there are a few genera that develop best in clean water with high concentrations of oxygen (González and Lozano, 2004). The larvae of the family Tipulidae are common in the sediments or among the leaves of the bottom of currents or drains, rotten trunks and other decomposing vegetal matter (Larza, Hernández and Carbajal, 2000).

Bed bugs (order hemiptera) have a size of 2 to 100 mm with or without wings, membranous posterior wings, and perforator-sucker buccal apparatus. In this order they include water scorpions, shoemakers, bed bugs, field bugs, triatomines, pentatomes (Hickman, Roberts and Larson, 2009). The suborder Heteroptera includes important aquatic insects that inhabit a wide range of aquatic ecosystems (freshwater, marine and interstitial environments and altitude). Most are predators and in some cases detritivores and alguivores such as those of the Corixidae family (Konopko and Melo, 2009). Aquatic hemiptera increase their abundance in systems with depths less than 1m.

The oxygen dissolved in the water allows these organisms to remain submerged longer, since their air bubble used for breathing lasts longer (Contreras, Navarrete and Lara, 2008); they also have other adaptations for breathing by taking oxygen from the air like anal tubes and abdominal canals (Roldan Perez, 1988). The presence of submerged aquatic vegetation decreases the predation of individuals of the Corixidae family (Contreras, Navarrete and Lara, 2008). Individuals of the Naucoridae family are entirely aquatic and are generally found in lotic and lentic systems, among vascular hydrophytes (Larza, Hernández and Carbajal, 2000).

Individuals of the gastropod class, mostly herbivores (Hickman, Roberts and Larson, 2009), feed on algae and various plant residues. They inhabit environments with dissolved salts, especially calcium carbonate, being indicators of alkaline water. Most species require high concentrations of oxygen (Roldan Perez, 1996).

Individuals of the order Tricladida (flat and flat body species) can reach 30mm in length. They are fundamentally carnivorous, most live under stones, leaves, branches and in shallow waters; their individuals require oxygenated water. However, some have the capacity to withstand contamination levels (Roldan Perez, 1996).

Individuals of the Nematomorpha class are called "horsehair worms", adult worms are between 10 and 70 cm long, have a fibrous cuticle; they live in clean streams, adhering to vegetation, under stones, on the banks of rivers and streams (Roldan Perez, 1988). They are organisms that need to complete their life cycle within an appropriate host.

Within the Hirudinea Class, individuals of the order *Glossiphoniforme*, called leeches, have sizes between 5 mm to 45 cm, their body is flat, and they have suckers that surround the mouth (Hickman, Roberts and Larson, 2009). Some feed on organic waste, but most are carnivorous. They perform gaseous exchange through the skin which has an innumerable amount of capillaries (Roldan Perez, 1996).

The Acari order (mites), belonging to the Arachnoidea Class, is a little known group, its individuals are globular, with cephalothorax and abdomen fused, its size varies between 0.4 and 3 mm (Hickman, Roberts and Larson, 2009). Water mites are found in most freshwater habitats, both in lentic and lotic environments.

The individuals of the Bivalva Class vary between 2 and 180 mm in length, are filters of plankton and detritus. Freshwater bivalves are organisms of both lotic and lentic water. They are found in muddy ecosystems, are abundant where the pH of the water is above 7.0 and where there is a large amount of carbonates.

2.3 The variability in the composition and structure of aquatic macroinvertebrates

The communities of benthic macroinvertebrates have been selected as one of the most relevant groups of organisms to assess the integrity of the ecological status of water bodies, since they have proven to be good bioindicators of the quality of the environment, by fulfilling some desired requirements such as sensitivity, feasibility of sampling, scientific validity, among others (González and Lozano, 2004).

However, despite the innumerable advantages of these organisms, it has been detected that seasonality may be a determining factor that influences the presence of certain groups or species, and the importance of determining the abundance and diversity of macroinvertebrates in relationship with the climate; this makes it clear that the structure and composition of macroinvertebrates does not vary only because of anthropic environmental impacts that affect water quality, but also show important variations as a consequence of the natural variability of environmental conditions in aquatic ecosystems (Chang et al., 2014).

Sometimes, this natural variability (intra-annual or seasonal and interannual) presented by aquatic macroinvertebrate communities does not allow to use the same criterion to evaluate the communities present in two different sections of a body of water, as well as in two different periods, generating a certain degree of uncertainty in the processes of evaluation of the quality of the medium (Loeb and Spacie, 1994).

Intra-annual variations tend to follow cyclical and directional patterns, which are relatively predictable, since they are mainly determined by the seasonal variation that the climate follows. However, the latter (interannual) are less predictable because they usually derive from phenomena generated on a larger scale, which do not follow a defined cyclical pattern (Reynoldson and Wright, 2000).

The temporal variation of the macroinvertebrate communities can interfere in the evaluation process of the ecological state of the bodies of water, even in the area of giving comparative results.

Some authors, who have addressed this problem, propose some points to take into account to reduce the effects that temporal variability could cause on aquatic macroinvertebrate communities. In such considerations, climate is usually the main factor for determining variants.

Therefore, the advantage of characterizing the community of macroinvertebrates at least at two seasons of the year with different environmental conditions is shown, this usually allows knowing how the community responds to a range of values of environmental variables, and thus the necessary comparisons to determine that their presence is due to pollution and not because of seasonality. Sporka et al. (2006) shows the advantages of working with databases that contain information from various times within the same year, since the climatic variations of recent times may be the key to having a margin of error when comparing previous studies.

In these cases, the collection field data should always be done at the same time of the year, so that the comparison between samples is sufficiently effective. For this, it is necessary to identify which is the time of the year in which the changes generated by the anthropic pressures in the macroinvertebrate communities are more notable and therefore easier to identify, in this case it would be necessary to place the monitoring preferably in the moments when the effects of these pressures are greater.

3 Environmental management and ecological river restoration processes

3.1 What is ecological fluvial restoration?

Environmental management is conceived as the integrated system of processes and actions aimed at achieving the environmental recovery of a degraded area or area based on a diagnostic analysis and planning. Within this framework, fluvial ecological restoration represents an important component of the environmental management process, which is aimed at achieving the recovery of the functional status of a body of water until reaching its ecosystemic functionality.

Restore consists of recovering a natural fluvial system eliminating those impacts or alterations that degrade it, thus allowing natural processes and balances to be restored, which in turn facilitate that system to function in a self-sustained manner over time (Herrera, 2013). However, this restoration process does not always allow to reach the original conditions of the system, transforming it in any way into a river of anthropocentric dynamics, instead of the ecocentric dynamics of water bodies in pristine or original states.

For a river to recover its natural functions, it must recover its flow and fluvial space in time, which in practice is impossible, but it is feasible to achieve approximation parameters as close as possible to the historical behavior of the river. This can be achieved satisfactorily insofar as the number of negative environmental impacts caused on the body of water is reduced.

An important element in the restoration process is the participation of the community, where the users of the resource should ask themselves: What river do we want? and according to this, the local actors define intervention ranges, which in turn determine the recovery degree of the body of water. This process must be accompanied by a strong component of environmental awareness and education towards the community that benefits from the resource in a certain area (Herrera, 2013).

3.2 Objectives of the ecological river restoration

The general objective of the fluvial ecological restoration is to recover the ecosystemic functionality of one or more bodies of water, both in their ecological and hydrogeological aspects, in such a way that these bodies recover their status as providers of ecosystem services to the environment and its different components.

To achieve this objective, it is necessary to identify the following aspects that directly influence the ecological and hydrogeological quality of the bodies of water: fluvial dynamics, local biodiversity, resilience, compatibility with the socio-economic and environmental environment, landscape environment, heritage and effective values, legislation, presence and typology of floods, relationship with employment in the area (Herrera, 2013).

Fluvial dynamics represents the capacity of a body of water to mark its trajectory according to a flow of flows and energetic dynamics of its water, depending on the slope and relief through which its water flows. This dynamic of physical expression plays a fundamental role in the nutrient cycle of the system, in its biological composition and in the erosion capacity of the river due to the impact strength of its water. This dynamic is translated, in the end, into the self-purification capacity of the river in the face of natural or provoked disturbances that the body of water may face (Elliot Munro, 2010).

The above is linked to the issue of biodiversity, which is also a very important aspect because it allows measuring and evaluating the ecological health status of an ecosystem and clearly reflects the effects caused by intervention activities. It is necessary to consider that not all the species that can be conforming the biota of a river are beneficial for the aquatic environment. Exotic or introduced species exist that can seriously affect the ecological health of the ecosystem, as is the case of some species of fish and aquatic plants, which sometimes threaten the population health of other homologous species or, can become invasive pests, difficult to control and that demand immediate management attention (Fernández, Leguizamon and Acciareci, 2015).

The recovery of the ecosystem (auto) functionality of a body of water is known as resilience, this condition allows to know in what capacity a body of water is to support levels of anthropic intervention or change factors of natural conditions and self-purification. This phenomenon is also closely linked to the processes or initiatives of ecological river restoration (Ferreira, 2012).

All fluvial restoration processes must take into account the socio-economic and landscape context in which it is developed, since the levels of intervention received by the body of water and the considerations depend on the interests of people associated with the dynamics of the river. For example, a landscape environment dominated by agricultural and livestock activities will not have the same environmental impact as a river that is surrounded by a town where buildings predominate. In addition, the conservation interests of the first are based on guaranteeing the supply of water in quality and quantity, because the community uses the water resource as a source of irrigation and watering hole for the animals. In the second case, it may not be very important to take care of the state of ecological health of the river because it surely has potable water and uses it instead as a waste sink; consequently, the purposes and actions of restoration have different scope, depending on the socio-economic interests of the surrounding population.

In some contexts, the presence of a river as part of its landscape environment represents an element of ethnographic and cultural wealth that, by tradition, deserves special treatment. In these cases, the river becomes a source of rituals and cultural customs (places of leisure, tourism, relaxation, spiritual recharge, etc.) whose considerations must also be taken into account when restoring it.

It is also necessary to observe the legislation (national, provincial, municipal) of each site or area to be restored to determine the scope and viability of it. Each state or province has its own legislative framework that regulates this type of activities according to the regulations of each country (Asamblea Nacional, 2010). For Ecuador, the law on water resources is the instrument that allows regulating the use and management of water resources at the national level, under the sole rector of the National Secretariat of Water (SENAGUA) and coordination with the Ministry of the Environment (MAE) as a national environmental authority.

Finally, a process of restoration demands intervention situations that are eventually complex and, in many cases, multidisciplinary, that require a certain amount effort. Therefore, restoration processes can generate sources of employment, in which the communities surrounding the intervention sites can be active participants in the engineering of the river restoration process (Figure 3).

Figure 3. Person from the Espejo community, Atacazo highlands, participating in a process of ecological restoration (reforestation with native species) on the banks of selected bodies of water.

3.3 Some strategies to restore a fluvial environment

To recover a fluvial space it is necessary to refer to historical information of the affected area or to be intervened. This will allow to have a point of reference on which the efficiency of the actions taken in terms of restoration will be measured, in the medium and long term. If it is not feasible to obtain this historical information, it will be necessary to make an analysis of the reference conditions of bodies of water near or close to the area of intervention.

One of the most important aspects is to establish a natural flow regime with the objective of not squandering enormous economic and human efforts on a zone or stretch of river in which the behavior and dynamics of floods are not known. From this knowledge depends the survival or shelter of the complementary species or works that are made in the restoration area.

The elimination of barriers or obstacles within the channel of the fluvial channel (Figure 4) is another aspect to consider due to the importance to maintain the hydric connectivity of the channel and in this way, favor the migration of species and the genetic interchange.

Figure 4. Presence of an artificial barrier placed in the bed of a highlands river (dam wall).

The establishment of natural hydrological protection zones in the form of strips parallel to the sides of the water channels usually help to retain sediments that could fall to the body of water, since the surrounding vegetation acts as a natural filter, retaining solids that could become causes of serious sedimentation processes of bodies of water. These hydrological protection zones should be structured by heterogeneous natural vegetation so that each of the plant species plays a specific role in the process of solid retention (Garcia de Jalón, 2003).

Occasionally and due to the damage caused in a certain stretch of river, it is necessary to resort to semi-natural plantations with species typical of the sector (Figure 3). This procedure is recommended when it is necessary to accelerate the restoration process against the prolonged time that would take a process of spontaneous natural regeneration of the affected environment. Normally, this type of procedure demands a prolonged monitoring to ensure the proper establishment of the species used to restore the aquatic environment.

An important aspect that is linked to the previous one is the creation and regeneration of microhabitats with the aim of recovering the natural biota of the place. This is based on the creation of microenvironments in which leaf litter is generated, which will increase the increment of organic load in the stretch of the river and the formation of silt, conditions that favor the spontaneous establishment of some species due to the availability of nutrients. This scenario can be beneficial for the creation of spawning areas and refuge for larger species such as fish.

Sometimes, it is necessary to recover the biodiversity of the altered place, for which it is valid to introduce again native vegetable species and with demonstrated dynamics of tolerance to contaminating factors (Yánez and Bárcenas, 2012), thus generating social and environmental benefits. In some cases, this scenario may be beneficial for productive activities in the area, since communities can use the resource directly or indirectly as a subsistence mechanism.

3.4 Bioengineering applied to river restoration

Bioengineering applied to the restoration and environmental regeneration of rivers consists of the use of live plants or parts thereof, together with other biodegradable materials (wood, rocks, blankets, organic networks, etc.) and other synthetic, usually photodegradable (geotextiles, polypropylene networks and geogrids), incorporating and taking advantage of local elements (soil topography, microclimate, etc.) to achieve structural objectives in a fluvial restoration process (Herrera, 2013). From this conceptualization, some authors conceive certain variations depending on the final result of the restoration process. Thus, if the purpose of restoration is to improve ecosystemic functionality, leaving out the use of structures or artificial inputs, this is called Eco-engineering. Other authors call this process naturalistic engineering.

This type of technique is used to accelerate the ecological recovery processes of a body of water, a process that nature would take much longer to recover. Conventional engineering differs because the criterion of the functionality of the physical infrastructure prevails, instead of prioritizing the ecosystemic functionality.

Among the techniques of naturalistic engineering the most outstanding are those that combine living plants with inert material such as sand, sticks, trunks, stones and earth. With this material it is possible to establish plantation or transplants of rhizomes, live tracings, trellis and live lattice.

On the other hand, and as part of bioengineering techniques, synthetic material can be used, mixed with living material. The most common forms are: application of plastic meshes, geomembranes, rolls of coconut fiber, gabions combined with bio-rollers, etc.

3.5 Management strategies for the application of bioengineering

In a restoration intervention, one must always bear in mind the precautionary principle so as not to underestimate the hydraulic potential of the river and, in turn, the regeneration capacity of the natural vegetation used for restoration. There are plants that grow faster and settle more easily than others, but not all go at the same pace. This supposes a process of progressive sowing and by short stretches, to be evaluating the result of prendimiento and adaptation of the new plants.

Before proposing the restoration actions, it is necessary to know perfectly the fluvial, hydrogeological and biological dynamics of the body of water to provide the best and closest approximation to their conditions of origin (Ollero, 2011).

It is also important after gathering information (historical, cartographic data, etc.) of the conditions of the area to be restored, performing an on-site analysis to verify that what is planned on paper will actually be adapted to the conditions of the particular site.

At the end of the process, the maintenance and sustainability of the actions is fundamental, especially during the first three to six months, during which most of the plant species planted in sectors contiguous to the river are established and manage to adapt to the environment conditions. After this time, it is recommended to structure a monitoring and follow-up program that includes at least one annual intervention and with the appropriate budget equivalent to 20% of the total value of the restoration (Herrera, 2013).

3.6 Citizen participation in the river ecological restoration process

The only guarantee to ensure the sustainability of river restoration interventions is citizen participation. By involving the inhabitants of the area, an empowerment of the initiative is achieved by the local actors frequently interested in maintaining a good quality of the bodies of water for different purposes (Nasimba, Yánez and Barros, 2017). To achieve this, the project must consider the active participation of community members, either in the planning phase or in the different phases of its execution (Ollero, 2011).

The socialization phase of the initiative is the most important aspect. In this way, the community becomes aware of the importance of the actions to be taken and how they benefit the landscape environment of the area, and ultimately, contribute to improving the quality of life of the population in the areas of influence of the bodies of water.

In this aspect, the initiative of the local governments with their different management figures at the local level is in charge of specific competences on these issues. The economic resources allocated for these activities must come from a budget item of the municipalities and the private sector, which guarantees the permanent availability of resources to ensure the sustainability of the initiative. The work must be multidisciplinary and can come from both the public and private sectors. After the intervention phase of the project, it is advisable to appoint citizen oversight and management commissions so that these associations are in charge of ensuring proper compliance with the planned activities and advocate for the continuity and sustainability of the initiative, which can be assessed in dependence on the application of multi-participatory strategies, but oriented towards the supervision and implementation of judicial measures vs. pollutant actors.

4 Conclusions

The present investigation has generated a theoretical frame of reference that seeks to contribute to river restoration initiatives in Ecuador especially, but not exclusively, in Andean environments. This first phase of the study allowed to compare information generated from the impacts caused by anthropogenic activity and its possible consequences on the ecological health status of primary water sources, using as environmental quality thermometers, the health state of the plant cover and water resources in terms of quality and quantity, with the support of aquatic bioindicators and basic physical-chemical environmental variables.

It is important to point out that this research constitutes a first phase of an institutional program of ecological restoration of primary water sources, led by the FONAG and in which the Atacazo microbasin has been selected as a pilot analysis unit at a local scale, after which results and favorable experiences will be replicated to other microbasins bordering the city of Quito. Results of this later phase are being systematized to be presented in future publications.

Although it is true that there are satisfactory results in this first phase of the project, it must be clear that river ecological restoration initiatives must yield favorable results in the medium and long terms and to achieve them, the initiative's empowerment will have to be achieved and local people, as a strategy to guarantee continuity of the initiative over the time. It must always be remembered that it is important to better manage the water collection works in the high zones, in order to cause the least possible damage to the ecosystem and the associated species, avoiding the interruption or interruption of the hydrological connectivity of the system.

At the municipal level, it is important that this type of river ecological restoration initiatives be inserted as a component within the environmental management plans that each local government (GAD) has to undertake in the territory of its jurisdiction, and be addressed as an initiative that requires permanent follow-up and monitoring to detect in a timely manner the changes that may occur in a certain area and take the appropriate management actions in a timely manner.

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