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Water quality assessment of rivers using macroinvertebrates in Latin America :

Progress report and focus on Mexico

sous la direction de Karl M. Wantzen

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- **Progress report and focus on Mexico -**

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TRAINING THROUGH RESEARCH, GRADUATION PROJECT IN PLANNING AND ENVIRONMENTAL ENGINEERING

Training in planning and environmental engineering, provided by the Planning and Environment Department of the Ecole Polytechnique of the University of Tours, combines in the field of urban planning, the planning of areas with high to low anthropisation, the acquisition of fundamental knowledge, the acquisition of techniques and know-how, training in professional practice and training through research. The latter does not aim to train only future students wishing to extend their training through doctoral studies, but while opening up this path, it aims first and foremost to foster the ability of future engineers to :

- Increase their skills in professional practice through the mobilisation of knowledge and techniques, the foundations and content of which have been explored as thoroughly as possible in order to ensure good intellectual and practical mastery,
- To increase the capacity of planning and environmental engineers to innovate both in terms of methods and tools, which can be mobilised to tackle and resolve the complex problems posed by the organisation and management of spaces.

Training through research includes an individual research exercise, the end-of-study project (P.F.E.), located in the final year of engineering students' training. This exercise corresponds to an internship of at least three months in a research laboratory, mainly within the Dynamiques et Actions Territoriales et Environnementales team of UMR 7324 CITERES, to which the teacher-researchers of the planning department belong.

The research work, the basic objective of which is to acquire methodological competence in research, must meet one of two main objectives :

- To develop all or part of a new method or tool for the innovative treatment of a spatial planning problem.
- To deepen basic knowledge to better address a complex planning issue.

In order to enhance the value of this research work, we have decided to put the dissertations on line on the basis of the University System of Documentation (SUDOC), starting from the mention good.

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SUMMARY

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LIST OF ABBREVIATIONS

AQEM : Assessment System for the Ecological Quality of Streams and Rivers throughout Europe using Benthic Macroinvertebrates
CONAGUA : Comisión Nacional del Agua
CONABIO : Comisión Nacional de Biodiversidad
DBO5 : Five-day Biological Oxygen Demand
DCO : Chemical Oxygen Demand
EPA : Environmental Protection Agency
EPT : Ephemeroptera, Plecoptera, Trichoptera
ESP : End of Study Project
GWW : Global Water Watch
IMTA : Instituto Mexicano de Tecnología del Agua
OSC : Organizaciones de la Sociedad Civil
PACD : Planes de aseguramiento de calidad de datos
TSS : Total suspended solid

LIST OF INDICES

ABI : Andean Biotic Index
ASPT : Average Score Per Taxon
BI : Biotic Indices of Communities
BIIM : Biotic Integrity Index of Macroinvertebrates
BIP : Biotic Index of Pollution
BISLS : Biotic Index for San Luis Sierras
BMI : Benthic multimetric index
BMPS : Biotic monitoring Patagonian streams
BMWP : Biological Monitoring Working Party
EBI : Extended Biotic Index
FBI : Family biotic index
FFG : Functional Feeding Groups
GMMI : Guapiaçu-Macau Multimetric Index
IBB : Indice Biotique Belge
IBE : Indice Biotico Esteso
IBI : Index biotic Integrity
IBIAMA : Index of Biotic Integrity for Aquatic Macroinvertebrate Associations
IBIAP : Biotic Integrity Index using aquatic invertebrates
IBMG : Indice Biotique Macroinvertébrés de Guyane
IBPAMP : Biotic Index for PAMPean rivers and streams
IBY-4 : Yungas Biotic Index based on 4 taxa
ICE : Índice de Calidad Ecológica
IMEERA : Índice Multimétrico del Estado Ecológico para Ríos Altoandinos
ISMR : Saprobic Index for Brazilian Rivers in Minas Gerais and Rio de Janeiro states
MBI : Sierra of San Luis Macroinvertebrates Biotic Index
MI : Multimetric index
MISB : Serra da Bocaina Multimetric Index
NLSMI : Biological Neotropical Low-land Stream Multimetric Index
PPPMI : Piabanha-Paquequer-Preto Multimetric Index
(P)CRBI : Proposed Costa Rican Biotic Index
SIGNAL: Stream Invertebrate Grade Number
SOMI : Serra dos Órgãos Multimetric Index
TSI-BI : Trophic State Index for Benthic Invertebrates

Introduction

We know that today biodiversity is increasingly at risk and faces multiple threats. Biological resources are declining due to human activities, particularly the biodiversity of freshwater ecosystems, which is extremely vulnerable (Dudgeon, 2006). Indeed, the latter shows a much greater decline than terrestrial or marine biodiversity. Faced with this observation, researchers are trying to find solutions to conserve these ecosystems, but freshwater ecosystems are under-represented in the scientific literature (Reid, 2018), which is why it is important to study this topic. Bioindicator organisms, especially macroinvertebrates, can be very useful in quantifying the ecological status of a lotic ecosystem. On the one hand, they increase our knowledge about them, but they can also support decision making when it comes to conservation, management or restoration actions. Latin America is particularly affected by these threats, since it is part of the group of countries called Global South, the developing countries. Indeed, these countries present additional stress factors compared to the Global North countries, such as the geopolitical and social context, the simultaneous arrival of all impacts on hydrosystems, a lack of management and resources (Wantzen and al., 2019).
The aim of this study is therefore to synthesise the knowledge of Latin American countries on bioindication by macroinvertebrates in order to know their capacity to assess the state and quality of their rivers and thus be able to manage them in the best possible way. This paper will focus on two main issues ;

- How advanced are Latin American countries in the development of bioindication methods?
- How can Mexico, a megadiverse country, develop a bioindication system compatible with the multiplicity of its ecoregions?

In order to answer these questions, the following work is carried out in two parts. First an inventory of the many methods of bioindication already existing in Latin America is made. Then, the document will focus on Mexico and its different points of vue and way to use macroinvertebrates bioindication to assess water quality and manage rivers.
The idea is ultimately to produce a synthetic document to help Mexico, one of the countries with the greatest diversity of hydro-ecosystems in the world, to choose the method best suited to its case and its aquatic ecosystems.

Part 1 - Macroinvertebrates bioindication in Latin America : context, challenges and progress report.

1. General context: bioindication in Latin America

As indicated previously, the subject of study of this ESP concerns the different methods of water quality assessment - bioindication or biomonitoring - used in Latin America. The subject being vast, this first part makes it possible to define the main terms and explain the issues before reducing it to a more specific case study.

1.1. Definitions

First of all, we are dealing here with aquatic ecosystems. An ecosystem is a functional system in which there is a cyclic exchange of matter and energy between living organisms and the abiotic environment. Consequently, biology and chemistry are closely linked and play complementary roles in the assessment of natural and polluted waters (Vammen and al., 2019). Aquatic ecosystems therefore refer to ecosystems characterized by the presence of water, whether it is current or not, such as lakes, swamps, rivers or other. They can be lotic or lentic systems. In this paper we will focus on lotic systems. They are defined as continental running water systems, i.e. rivers.

Biomonitoring or bioindication is generally defined as "the systematic use of living organisms or their response to determine condition or changes in environment" or as "a method of observing impact of external factors on ecosystems and their development over a period, or of ascertaining differences between one location and another" (Li et al., 2010). These methods are based on the use of so-called bioindicator species. A bioindicator is "an organism (or part of an organism or community of organism) that contains information on the quality of the environment (or a part of the environment)(Li et al., 2010). As a result, their presence or absence gives information about characteristics of the habitat and the quality of the system. To monitor river quality, several indicators can be used; plants, fishes, macroinvertebrates, periphyton and others. For example, in France the most used methods are IPR (Indice Poisson Rivière), IBMR (Indice Biologique Macrophyte en Rivière) and l'I2M2 (Indice Invertébré Multi Métrique).

Aquatic macroinvertebrates are all the organisms that live at the bottom of rivers and lakes, attached to aquatic vegetation and submerged rocks (Roldán, 1988). They represent all of the aquatic invertebrate animals visible to the eye, with a size greater than 0.5 mm and which do not have a skeleton. Macroinvertebrates include insects (larva, nymph, adult) as well as molluscs, worms or crustaceans, and are widely used in bioindication to assess the quality of water and habitats (González, Roldán, 2019).

With regard to Latin America (Figure 1), it is generally defined as the part of America in which the countries have Roman languages as their official language, i.e. derived from Latin, namely Spanish, Portuguese and French (https://fr.wikipedia.org/wiki/Am%C3%A9rique_latine).

Figure 1: Map of Latin America and its constituent countries

1.2. Short review: bioindication of lotic systems by macroinvertebrates

The macroinvertebrates both integrate environmental changes in their habitat physical point of view, chemical and ecological through space and time which gives many benefits to use (Bassets et al., 2004; Forde, 2019). Their omnipresence and sedentary behavior is a first advantage for the spatial analysis of pollutants. In fact, unlike fish which are very mobile and which, in the event of pollution, can move to escape and then return, macroinvertebrates are much less mobile and cannot escape from it. Thus the composition of the benthic invertebrate assemblage is limited by the environmental impacts. Species that are sensitive to pollution or physical habitat changes will disappear in an impacted site, which can be evidenced when comparing this site to a pristine reference site. Consequently, if the expected procession of

species is not found in a given place, it is possible to highlight the impact, the presence of pollution and habitat degradation.
In addition, macroinvertebrates have a relatively long life cycle (especially for large bodied, temperate zone species) which allows temporal analysis of the disturbance. Their larval stage can go from a few months to three years so their absence can testify to a pollution which goes back to a very earlier date. Another advantage lies in the ease of sampling which consists in removing substrate and does not require complex and more dangerous techniques such as electric fishing. However, they require a high degree of taxonomic knowledge to be able to identify them and carry out bioindication.

1.3. Context and challenges of the present study

Aquatic ecosystems are among the most important biological resources on the planet, essential for both humans and biodiversity (Moya et al., 2007). Indeed they provide many ecosystem services such as water filtration and purification, carbon dioxide capture at peatlands, regulation of floods in buffer zones, development of biodiversity and many others again.

However, they are also among the most endangered ecosystems, partly because human populations and activities have long developed along rivers and continue to exploit this fragile resource more and more. Increasingly anthropized, natural and intact watercourses are gradually disappearing in favor of rectilinear channels, with a homogeneous and dammed bed, and the general quality of water bodies in the world are decreasing sharply (Helson and Williams, 2013)

The preservation of aquatic environments in good condition as well as the implementation of effective management practices on altered systems have therefore become a priority to ensure the restoration of their integrity and their return to good ecological status. At present this awareness and these concerns are translated by many countries by the establishment of law and regulation.

In order to act, it is first of all essential to understand the relationship between human-induced disturbances and their effects on aquatic ecosystems in order to better understand them. Then, in order to assess and monitor the ecological quality of water bodies, methods for quantifying and interpreting the results of biological studies must be developed and among them, bioindication or biomonitoring methods.

Countries of the Global North were the first to substantially pollute their Aquatic Ecosystems and also were the first to begin with restoration activities (Buss, 2015). A great problem in countries of the Global South is that, due to fast development, different types of pollution (that could have been tackled in the North one by one) occur simultaneously, while the administrative structures and the financial-political situation is often hampering similar initiatives in the Global South (Wantzen et al., 2016, 2019)
Recognizing the need to assess water quality, several countries in South America have carried out water quality analysis using the methodologies developed in Europe and North America (Damanik-Ambarita, 2016). The countries of Latin America have therefore not necessarily developed their own bioindication methods but have transferred those from countries that already have it, for economic reasons. As a result, the NAFTA states tend to have a strong influence on American methods, such as the IBI and US-EPA methods, while the MERCOSUR

states tend to collaborate more with the European partners who have developed many indices (BMWP, Saprobienindex, IGBN, AQEM project etc.).

However, for some Latin American countries, few adaptations of these indices have been made due to the lack of knowledge on the taxonomy, distribution and tolerance to pollution of macro-invertebrates in the region (Forde et al., 2019). Thus the direct application of these foreign methods to the rivers of Latin America is complex. Indeed, these biological indices are generally based on the tolerance values of taxa to water pollution. However, the same taxon present in two different countries does not necessarily have the same ecological characteristics and does not necessarily adapt in the same way to changes in the environment. Moreover, since these tolerance values have been determined for fauna living in temperate zones, it seems complicated to transpose them directly to taxa in Latin America (Moya et al*.*, 2007).

It therefore seems necessary to carry out an inventory of the methods used in Latin America in order to identify the countries, having or not adapting these different indices in order to better understand the assessment of the quality of the rivers in this region of the world. This study exclusively focuses on water pollution. Rapid assessment of habitat quality was not part of this study. Physical habitat pollution by light, which is an important issue in urban stream ecology (see Wantzen et al. 2019 for a short review) is not dealt with. The effects of siltation (i.e. increased suspended and bedload) as a result of erosion from agriculture and mining have been studied (see Wantzen and Mol, 2013), and an index has been developed by Wantzen (2006).

2. Research methodology

The resources we have used are the following: the bibliography given by M. Wantzen, Google scholar, ResearchGate, scientific journals from Latin America, and the bibliography of articles already used.

The strategy adopted to carry out this work was first of all to approach the situation of North and South America concerning the bioindication, for that we based ourselves interon the book "*Calidad del Agua en las Américas - Riesgos y Oportunidades"* published in 2019 by the IANAS (Water Committee of the Inter-American Network of Academies of Sciences) and co-written by numerous authors (Gabriel Roldán (Colombia), Katherine Vammen (Nicaragua), Henry Vaux (USA), Ernesto González (Venezuela), Ricardo Izurieta (Ecuador), José Fábrega (Panama) and Pablo Pastén González (Chile)). This allowed us to realize the general context of the study. To find this, one of our first effective searches was the query "*Calidad del agua en las Américas* " on Google Scholar. As expected, there were many results but most focused on more economic and political issues that were not appropriate for our subject.

Then we started looking for country by country information with keywords in Spanish or English like "*macroinvertebrados", "bioindicación", "calidad del agua", "métodos de evaluación ecológica"* by adding the name of the country we wanted to get the information. An example of a request could be: "*Bioindicación de la calidad del agua macroinvertebrados Brasil"* or "Biomonitoring macroinvertebrates Brazil". We realized that some authors were recurring like Gabriel Roldán-Perez, Alonso Ramirez, D. Baptista, MV Junqueira, MT Barbour. So we also looked for articles on their personal Google Scholar page. The journal

Hidrobiologica has also been an important source of information since it specializes in biodiversity and bioindication by macroinvertebrates in Latin America.

To find information about the characteristics and description of indices for Part III, searches were done to find the first article to create the index and then other more recent articles which showed its use in other regions. The goal was to first find the source article in order to name the authors and the year of creation and then to show its use through more recent articles. For this, we focused mainly on research in English first, then in Spanish when no results were found. The queries related to the full name of the index followed by its acronym, for example "*Biological monitoring working party BWMP"*. If the articles found were not the original one, as for the BMWP which presents many results, the year of creation or the author were added to the query.

3. Census of bioindication methods via macroinvertebrates in Latin America

The inventory of different bioindication methods based on the use of macroinvertebrates in Latin America (Table 1) made it possible to note the state of progress of each country in the adaptation of these methods.

It appears that the first Latin American countries to be interested in macroinvertebrates are Colombia and Brazil which, from the years 1980-1990, published their first works on bioindication and macroinvertebrates. (Forde et al., 2019). For most of the countries, the first publications were made around 2010 and research continues even today. Of the 22 Latin American countries identified, however, there are 4 countries with few records of benthic fauna and for which little or no information has been found (Guyana, Haiti, Dominican Republic, Jamaica and Suriname). Some authors (Bastardo,Sánchez-Rosario, 2017) deplore this gap, especially for Haiti and the Dominican Republic where "the fauna of the aquatic macroinvertebrates collected to date [...] is described as the richest Caribbean".

For the countries which have implemented bioindication methods by macroinvertebrates, it is possible to note that 7 countries out of 22, or 32%, directly apply and transpose the methods previously developed (Figure 2) while 7 others adapt them (32 %) and that the last 8 (36%) adapt some and apply others directly. In addition, for countries using, partially or totally, already existing methods, some are based on work carried out by Western countries or the United States while others are based on work carried out by Latin American countries.

The methods applied without adaptation used in Latin America are mainly; BMWP (Biological Monitoring Working Party), FBI (Family biotic index), IBI (Index biotic Integrity), FFG (Functional Feeding Groups), EBI (Extended Biotic Index), IBB (Indice Biotique Belge), IBIAMA (Index of Biotic Integrity for Aquatic Macroinvertebrate Associations), ASPT (Average Score Per Taxon) and SIGNAL (Stream Invertebrate Grade Number).

The most often adapted method is the BMWP method, followed by the IBF method. Finally, the bioindication methods from Latin America, modified from foreign methods, the most used are the BMWP-CR and the BMWP-Col from Costa Rica and Colombia respectively.

In the end, therefore, we note that 16 countries out of the 22 concerned, or 73%, have developed their own methods of assessing water quality using macroinvertebrates or an adaptation from a method developed by pioneer countries. Even if some have only developed one yet, this remains a sign of the country's involvement and a desire to improve their

techniques. Other countries such as Brazil, Argentina, Ecuador and Colombia are very involved and have already published several methods (Figure 3).

In the same way, certain authors also seem to be very involved in this kind of research. For example Baptista, D.F wrote many publications about macroinvertebrates in Brazil or Miserendino and Pizzolon since 1999 in Patagonia.

In addition to the indices set up at the country level, there are some developed for all of the Andes. Indeed the Andes Cordillera represent a mountainous ecosystem crossing, from North to South, west of South America and crossing the 7 countries that are Venezuela, Colombia, Ecuador, Peru, Bolivia, Chile and Argentina. Several clues concerning this region exist, we find; the Biotic Monitoring Patagonian Streams (BMPS) created in 1999, the IBY-4 in 2011, el Índice Multimétrico del Estado Ecológico para Ríos Altoandinos (IMEERA index) in 2013 and finally the Andean Biotic Index (ABI) created in 2014.

Location	Method used		Source
	Developed outside Latin America and applied as it is	Developed outside Latin America but applied with an adapted version or created in Latin America	
The Andes : (Venezuela, Colombia, Ecuador, Peru, Bolivia, Chile, Argentina)	/	Andean biotic index (ABI) Biotic monitoring Patagonian streams (BMPS) Índice Multimétrico del Estado Ecológico para Ríos Altoandinos (IMEERA) IBY-4	Ríos-Toum et al., 2014 Miserendino and Pizzolo,1999 Christian Villamarín et al., 2013 Dos Santos et al., 2011
Argentina	/	Biotique Carcarana Index Biotic Index for PAMPean rivers and streams (IBPAMP) Biotic Monitoring Patagonian Streams (BMPS) Sierra of San Luis Macroinvertebrates Biotic Index (MBI) Biotic Index of San Luis Sierras (BISLS)	Gualdoni, Oberto, 1998 Alberto Rodrigues et al., 2001 Miserendino and Pizzolón, 1999 Calderon et al., 2014 Calderon et al., 2017
Belize	SIGNAL 2	/	Arevalo, 2014
Bolivia	MI		Moya, 2007

	BMWP ASPT FBI	IBI	Moya et al., 2011
Brazil	IBE BMW ASPT EPT Saprobic Index	BMI (Benthic multimetric index) SOMI (Serra dos Órgãos Multimetric Index) GMMI (Guapiaçu-Macau Multimetric Index) PPPMI (Piabanha-Paquequer-Preto Multimetric Index) Serra da Bocaina Multimetric Index (MISB) BMWP-CETEC IBE-IOC	Ferreira et al., 2011 Baptista et al., 2007 Oliveira et al., 2011 Baptista et al., 2011 Baptista et al., 2013 Junqueira et al., 1998 Mungnai et al., 2008 Docile and Figueiró, 2013 Cummins et al., 2005
Chile	FBI IBE BMWP SIGNAL	ChFBI	Cordova et al., 2009 Alvial et al., 2012
Colombia	BMWP IBB FBI EPT BI	Index of Calidad Ecológica (ICE) BMWP-col ASPT-col	Forero et al., 2014 Roldán-Pérez, 2016 Lopez Erazo et al., 2015
Costa Rica	IBB IBG BMWP ASPT	BMWP-CR	Gutiérrez-Fonsec and Lorion, 2014
Cuba	/	BMWP-Cub	Naranjo Lopez et al., 2005
Ecuador	BMWP SIGNAL FBI	BMWP-Col BMWP-CR Biological Neotropical Low-land Stream Multimetric Index (NLSMI) Biotic Integrity Index using aquatic invertebrates (IBIAP)	Damanik-Ambarita et al., 2016 Holguin-Gonzalez et al., 2013

Guatemala	/	BMWP-CR, BMWP-Col. FBI-SV BMWP / Atitlán index	Morales and de Fátima, 2012
French Guiana	/	Macroinvertebrate Biotic Index (IBMG)	Dedieu et al., 2015
Honduras	FBI BMWP	/	Álvarez et al., 2007
Mexico	IBI BMWP FBI EPT MI IBE IBIAMA	/	Brain et al., 2002 Rosas-acevedo et al., 2014
Nicaragua	IBE FBI	BMWP-CR	Rosales and Sánchez Mateo, 2016
Panama	/	BMWP-PAN Biological Neotropical Low-land Stream Multimetric Index (NLSMI)	Selles and Vega, 2009 Del C. Guinard et al., 2013
Paraguay	/	BMWP / Aguapey	Galeano Molinas, 2018
Peru	BMWP	/	Paredes et al., 2005
Puerto Rico	/	BMWP-PR FBI-PR	Gutiérrez-Fonseca,Ramírez, 2016
Dominican Republic	BMWP	/	Soldner et al., 2004
Salvador	/	BMWP-CR FBI-SV-2010	Chávez Sifontes et al., 2010
Uruguay	/	Trophic State Index for Benthic Invertebrates (TSI-BI)	Chalar et al., 2011
Venezuela	BMWP FBI	/	Barrio and Rodríguez, 2013

Table 1: Summary of bioindication methods used in Latin America

Countries that do not use any macroinvertebrate bioindication methods

Countries using a macroinvertebrate bioindication method developed outside Latin America, without modification (BMWP, ASPT, FBI, SIGNAL, etc.)

Countries that have created their own method of bioindication by macroinvertebrates or have developed an adapted version of a method developed outside Latin America

Countries using both macroinvertebrate bioindication methods unmodified from those of other countries and methods specifically created or adapted

Figure 2: Map representing Latin American countries, whether or not they have adapted methods from pioneer countries

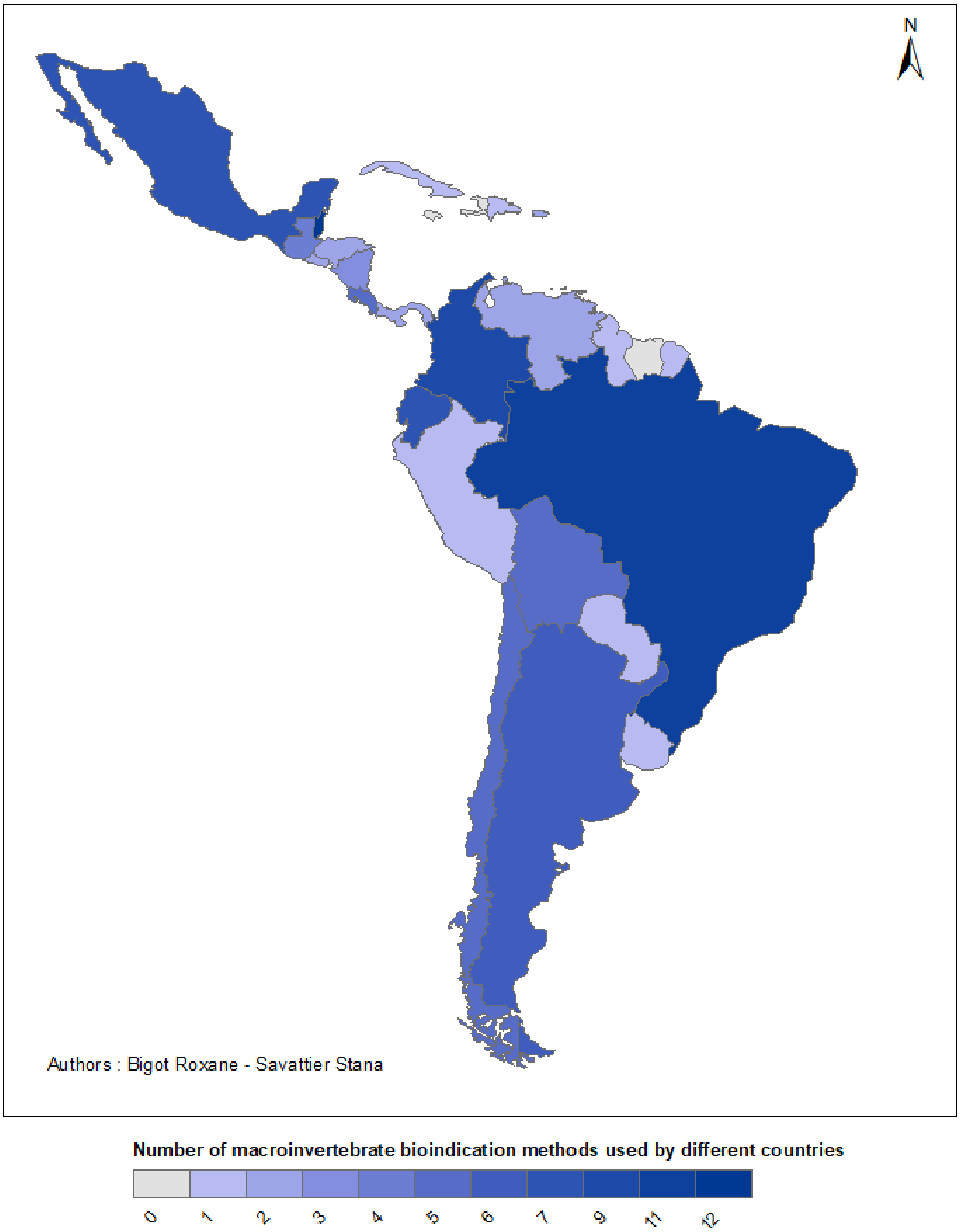

Figure 3: Map representing the number of bioindication methods implemented by different Latin American countries

4. Ecological characteristics and functioning of the various indices identified

In this part, the indices were this time analyzed from the point of view of their functioning. The work carried out here therefore made it possible, for each index, to identify the ecological bases on which they are based and their functioning. The main types of bioindication methods developed by pioneering countries such as those of Europe or the United States are first presented before looking in more detail at the different methods developed in Latin America. All these results are finally summarized in Table 4.

4.1. The main types of bioindication methods from pioneer countries

Even if in this study all the bioindication methods are based on the use of macroinvertebrates, sampling and analysis of data after sampling do not work in the same way for all methods. This section therefore seeks to explain in broad outline the different principles followed by the methods identified in order to better understand those developed specifically for Latin America.

4.1.1. Scoring methods: BMWP, ASPT, FBI, IBE

These methods are based on the attribution of a score, generally going from 0 to 10, for each benthic macroinvertebrate according to its tolerance at different levels of impact (Docile and Figueiró, 2013). The more sensitive the taxon to pollution, the higher its score and the less it is resistant to pollution the lower it is. It is then a question of carrying out a sampling on the ground and of adding the scores obtained for each macroinvertebrate according to the criterion presence / absence in order to obtain a final note. A high final score therefore indicates a slightly polluted environment because it hosts species sensitive to pollution.

Scoring methods date back to the early days of biomonitoring, beginning with the “Artenfehlbetrag” (number of lacking species, Kothé, 1957) and the saprobic index since the 1960ies, which evaluated the organic pollution by associating both an index value and a statistic weight to individual species (Friedrich, 1990). An attempt was made to introduce this precise method in two Brazilian states in the 1990ies (Junqueira et al. 2010), however it turned out to be difficult as it requires precise identification of invertebrate insect larvae (which often not possible or time-demanding).

The BMWP or Biological Monitoring Working Party was developed in Great Britain in 1978 by a group of researchers (Hawkes, 1998), it was not officially published in its original version but first underwent some modifications. This index was widely used and adapted for many European countries such as Spain in 1988 (BMWP'). It also served as a basis for adaptations outside Europe, among which the BMWP-CETEC for Brazil (Junqueira et al., 1998), the BMWP-Cu and the BMWP-Col for Colombia (Roldán-Pérez, 2016). Indeed, this index is used by many countries in Latin America, as shown in Table 1. However, it requires adaptations since macroinvertebrates may be absent from the region considered, replaced by other taxa, as well as families may have different pollution tolerances between regions

(Roche et al. 2010). To be able to adapt it to Latin American countries, it is therefore necessary to reassess the scores assigned to each taxon.

Even if this method is easy to set up because the determination is made only with the family of many critics were expressed in particular because the abundance is not taken into account (Hawkes, 1998), the sampling is not normalized and the sampled area is not taken into account (Pineda-Pineda, 2018). To solve this problem, many researchers have proposed improvements to this index, such as the ASPT or Average Score Per Taxon by Armitage et al. in 1983. The principle of ASPT is the same, the taxa scores are added but this time if the result is divided by the total number of taxa present in the statement in order to obtain a more representative result (Table 2).

ASPT value	<4	4-5	5-6	> 6
Water	Severe pollution	Moderate pollution	Questionable quality	Unpolluted

Table 2: Summary of the ASPT values obtained and their associated water quality

Another index using the scoring is the FBI or Family Biotic Index, created in 1989 by Plafkin et al. The principle is the same each taxon is associated with a score, thus:

$$FBI = \sum \frac{x_i t_i}{n}$$

Where xi = number of individuals of the taxon i
ti = tolerance value of the taxon i
n = total number of individuals present in the statement

The Biological Extended Index (IBE) is also a scoring method (Pennelli, 2006) developed for the first time by Woodiwiss in 1978 for European countries and then adapted for several Latin American countries.

The level of taxonomic determination was adapted from the classic IBE for Argentina in 2001, it then became IBPAMP and then for Brazil in 2006 (IBE-IOC) by R. Mugnai, RB Oliveira, A. do Lago Carvalho and DF Baptista: certain taxa must be determined by genus or family. The result is given by a double entry table taking into account abundance and the number of gender / family which gives a score (Ghetti, 1997). These scores are then associated with a quality class (Table 3).

System of conversion of the numerical values of IBE-IOC into quality classes, adapted for rivers of the Serra dos Órgãos, RJ, Brazil.

IBE-IOC value	Quality class	Description	Color
10, 11, 12, 13, 14	I	unpolluted	blue
8, 9	II	slightly polluted	green
6, 7	III	moderately polluted	yellow
3, 4, 5	IV	heavily polluted	orange
1, 2	V	very heavily polluted	red

Table 3: Association table between score and quality class - Mugnai et al., 2008

4.1.2. Multimetric indices: IBI

The evaluation method here consists of choosing significant metrics through statistical tests. These metrics are then calculated on so-called reference rivers, that is to say which have not undergone any disturbance, then for the river to study. Metrics are then compared in order to know whether or not they belong to the reference statistical distribution. The aim is here to know whether the values obtained for the study river correspond to the expected reference values. To do this, the results obtained for these metrics are converted into probabilities which correspond to the observation of a lower or higher metric value than the reference. These probabilities varying between 0 and 1 are then summed and the result will decrease when anthropogenic disturbances increase (Moya et al., 2007).

The Index of biotic Integrity (IBI) is a method based on the statistical description of sampling which makes it possible to assess the biotic integrity of aquatic ecosystems. Aquatic integrity is defined as "the capacity of an environment to support and maintain a balanced, integrated and adaptive community of organisms with a species composition, diversity and functional organization comparable to that of natural habitats in a region."(Karr, 1991). Its innovative value was that it combines the assessment of the quality of the habitat with the presence/absence of sensitive taxa. Moreover, when integrated in a rapid assessment protocol (RAP, Plafkin et al., 1989), it can deliver very fast results and/or allow to cover larger areas with a lower amount of manpower than the purely biotic indices that require a more detailed identification of taxa.

This index, very widespread in the United States, was initially created there in 1986 but was then based on the use of fish as a bioindicator species. It was then adapted to macroinvertebrates in many countries from 2002 and still continues to be further refined. Indeed, the IBI index is a specific index and must therefore be adapted to the region and the environment that one wishes to study (Adam et al., 2019).

The IBI was adapted for Latin America for the first time in Brazil (Wantzen, 1998), and later, in Bolivia in 2007 (Moya et al., 2007). This index aims to enable the assessment and protection of lowland rivers in Bolivia. It is based on the use of 8 local metrics for habitat and 5 for the structure and functioning of macroinvertebrate communities. Concerning the latter, these are the metrics: number of Ephemeroptera, Plecoptera and Trichoptera (EPT), abundance and relative abundance of EPT, abundance and relative abundance of Chironomidae.

4.1.3. Biotic indices:

The main difficulty in setting up biotic indices is the production of a standardized table allowing the index to be calculated. It is a table with two entries which contains, in the first column, the macroinvertebrates chosen when the index was created. They are then classified in order of decreasing sensitivity to pollution, from the most sensitive to the least sensitive. On the first line of the table we find the number of systematic units present in the sampling, that is to say the number of macroinvertebrates belonging to the order, family or genus chosen. In each table is then a score, indicating the quality of the environment.
To determine the score associated with a river under study, first identify and count each category of macroinvertebrate. The next step is to find the macroinvertebrate family appearing at the highest possible level in the table, associate the number of individuals found with it and read the score obtained. The different scores are divided into classes, generally ranging from very poor to very good, even though their names may differ from one method to another, which make it possible to know the quality of the aquatic environment studied.

Numerous biotic indices of families have been created, in France we find in particular the IBGN (Indice Biologique Global Normalisé). In Latin America, several countries such as Mexico, Guatemala, Honduras, El Salvador, Puerto Rico, Venezuela, Colombia and Chile use its methods to assess the quality of their water (Table 1).

4.1.4. Methods based on feeding behavior: FFG

This approach, based on the study of macroinvertebrate feeding habits, was introduced by Rich Merritt and Kenneth Cummins and collaborators in 1973 (Ramírez and Gutiérrez-Fonseca, 2014) as a tool to facilitate the incorporation of macroinvertebrates into the study of aquatic systems. It differs from other common bioindication techniques that rely on the taxonomy of the species present to study the quality of the aquatic environment. The book "Introduction to the Study of Aquatic Insects of the USA", first published in 1978, has been the reference for the study of benthic insects in entire Latin America for several decades, as comprehensive revision such as the series "Aquatic Biodiversity in Latin America" (e.g., were lacking for a long time). This often resulted in erroneous identification of animals and in wrong attribution to functional feeding groups. Only in 2005, an attempt was made to attribute Brazilian species to the FFG concept (Cummins et al. 2005), however, it has to be noted that the FFG concept is based on the assumption that a certain shape of mouth parts is conducive to the feeding behavior and diet type. This is not necessarily the case, as it has been shown in direct observations and stable isotope analysis (Wantzen and Wagner, 2006 and Marchese et al., 2015).

In macroinvertebrates there are 6 groups defined according to their way of collecting food which are; grazers (grazers and scrapers) which feed on algae and organic substances attached to the substrate, piercers (piercers) which feed on liquids contained in vascular plants, shredders (shredders) which feed on organic matter such as leaves or small pieces of wood. The collectors are divided into two sub-groups, the grazing collectors that collect particles accumulated on the bottom of the river and the filter collectors that capture organic matter particles directly in the water column. Predators feed on other organisms using

different capture techniques. A final group includes other types of macroinvertebrates such as omnivores or those that do not fit exactly into one category.

The first studies using FFGs were based on work on the classification of temperate regions. Since 2006, however, research efforts have identified the membership of Latin American macroinvertebrates in these groups, and the list currently established can be consulted in Appendix 1. Analysis of their stomach contents provides information on their position in the trophic chain (Ramírez, Gutiérrez-Fonseca, 2014). In order to know their feeding methods, it is also necessary to study the mouth parts and forearms that are used to capture food.

The concept of "River Continuum" (Vannote et al., 1980) is also considered in this method. The latter associates for each area, from upstream to downstream, the groups of invertebrates theoretically present and their ratios. Thus, if the location of the study stream in relation to this distribution is known, it is possible to see if these groups are, or are not, present and to compare the groups found with those expected. Thus "changes in the composition of FFGs can be used as an indicator of ecosystem change and recovery from disturbance" (Ramírez and Gutiérrez-Fonseca, 2014).

This method is not strictly speaking a bioindication method, as it does not lead to a given river quality rating or class, but allows an initial assessment of the state of the river to be made, using a simpler method because it is less demanding and less costly to determine. It should be noted, however, that this concept of "River Continuum" is not applicable everywhere. Contrary to the predictions of the RCC, tropical streams are often more based on algal biomass or on non-leaf litter than in temperate regions (Wantzen and Wagner, 2006 and Lau et al., 2009).

4.2. Methods used in Latin America

In this section, the functioning and ecological bases of the different methods of bioindication via macroinvertebrates used in Latin America are first briefly presented (Table 4, 5, 6) before being discussed in more detail, one by one.

Following the study of Table 4, 5 and 6, it can be seen that score-type methods and multimetric index-type methods are the most widespread in Latin America.

Index	Country/Author and year of creation	Use in Latin America	Method	Identification level	Result
Biological Monitoring Working Party (BMWP)	Great Britain, 1978	Without adaptation (Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, Honduras, Mexico, Peru, Dominican Republic, Venezuela Adaptation : BMWP-Col (Colombia, Guatemala and Ecuador), BMWP-CR (Costa Rica and Guatemala) , BMWP/Atitlan (Guatemala), BMWP-PAN (Panama), BMWP-Cub (Cuba), BMWP-PR (Puerto Rico), BMWP/Aguapey (Paraguay), BMWP-CETEC (Brazil)	Scoring	Family	Score : 0 - 150 Associated quality class
Average Score Per Taxon (ASPT)	Great Britain, 1983	Without adaptation (Costa Rica, Brazil, Bolivia) Adaptation : ASPT-Col (Colombia)	Scoring	Family	Score : 0 - 10 Associated quality class
Family biotic index (FBI)	America, 1982 Author : Hilsenhoff	Without adaptation (Bolivia, Chile, Ecuador, Honduras, Mexico, Nicaragua, Venezuela) Adaptation : FBI-SV-2010 (Guatemala), FBI-PR (Puerto Rico), ChFBI (Chile)	Scoring	Family	Score : 0 - 10 Associated quality class
Indice Biotico Esteso (IBE)	1978 Author : Woodiwiss	Without adaptation (Brazil , Chile, Nicaragua, Mexico) Adaptation: IBE-IOC (Brazil)	Scoring	Family	Score : 1 - 14 Associated quality class
Andean Biotic Index (ABI)	The Andes, 2014	Ecuador, Peru	Scoring	Family	5 associated quality class
Biotic monitoring Patagonian streams (BMPS)	Patagonia, 1999	/	Scoring	Family	Score : 0 - 150 5 associated quality class

Table 4: Summary of biological indices using scoring method identified in Latin America and how they work

Index	Country/Author and year of creation	Use in Latin America	Selected Metrics	Identification level	Result
Index biotic Integrity (IBI)	United-States, 1986	Without adaptation Adaptation: Bolivia (2007)	EPT number, abundance and relative abundance for EPT and Chironomidae	Order Family	For Bolivia : 0,8 to 4 5 associated quality class
Índice Multimétrico del Estado Ecológico para Ríos Altoandinos (IMEERA-B)	The Andes, 2013	The Andes	EPT %clinger %climbers intolerant taxa ABI % intolerant taxa	Order Family Genus	Score : < 22 to > 73 5 associated quality class
Índice Multimétrico del Estado Ecológico para Ríos Altoandinos (IMEERA-P)			Total number taxon Number intolerant taxon ABI, % taxon tolerant		Score : < 48 to > 99 5 associated quality class
Serra dos Órgãos Multimetric Index (SOMI)	Brazil, 2006	/	% Diptera, % Coleoptera, Family Taxa, EPT Taxa, BMWP-CETEC and % Shredders	Order Family Genus	Score : 6 - 30 4 associated quality class
Benthic multimetric index (BMI)	Brazil, 2011	/	family richness %Oligochaeta, % Chironomidae + Oligochaeta (% CHOL) % EPT % Collector-gatherers	Order Family	Score : 6 - 30 4 associated quality class

Biotic Integrity Index using aquatic invertebrates (IBIAP)	Ecuador, 2008	/	Species richness Number of EPT taxa Number of filterers and shredders The mean pollution tolerance of the sample	Family Genus Species	Score : 0 - 16 4 Associated quality class
Indice Biotique Macroinvertébrés de Guyane (IBMG)	Guyana, 2015	/	Chao1 Log.Elmidae Number of Coleopteran families %collector-gatherer %Ephemeroptera and Trichoptera Shannon index	Family	Score : 0 - 1 5 Associated quality class
Guapiaçu-Macau Multimetric Index (GMMI)	Brazil, 2011	/	Trichoptera family richness Shannon family diversity % Plecoptera individuals %EPT individuals % mollusk % Diptera individuals % shredder individuals proportion Chironomidae/Diptera individuals, proportion Hydropsychidae/Trichoptera individuals.	Family, Genus	Score : 0 - 100 5 Associated quality class
Piabanha-Paquequer-Preto Multimetric Index (PPMI)	Brasil, 2011	/	Family richness Shannon-Wiener family diversity, EPT family richness %Diptera %MOLD (Mollusca + Diptera) and %Collectors	Family, Genus	score: 0 - 100 5 Associated quality class
Biological Neotropical Low-land Stream	Panama, 2013	/	%of scrapers Margalef's index (taxa)	Branch, Order, Family, Genus	score : 0 - 10
Multimetric Index (NLSMI)			ratio of Chironomidae/Diptera individuals number of EPT % Trichoptera % shredders Shannon's evenness index		5 Associated quality class
MISB	Brasil, 2013	/	Taxonomic richness trichoptera richness % beetles % diptera IBE-IOC index ratio EPT / Chironomidae	Family, Genus (Trichoptera)	Score : 0 - 100 5 Associated quality class

Table 5: Summary of biological indices using the Multimetric Index approach identified in Latin America and how they work

Index	Country/Author and year of creation	Method	Selected Metrics	Identification level	Result
Trophic State Index for Benthic Invertebrates (TSI-BI)	Uruguay, 2011	Multiparameter Index - Score	Phosphorus content, optimum, tolerance of macroinvertebrate taxa	Genus	Score : < 6 to > 8 3 associated trophic groups
Índice de Calidad Ecológica (ICE)	2014	Multiparameter Index - Score	Physico-chemical variables, abundance and tolerance of macroinvertebrates	Genus, Species	3 categories of ecological status
Yungas Biotic Index based on 4 taxa (IBY-4)	Andes, 2011	Biotic index	4 taxa (Elmidae, Plecoptera, Trichoptera and Megaloptera)	Order, Family	Rating : 0 - 4 4 Associated quality class
Biotic Index for PAMPean rivers and streams (IBPAMP)	Argentina, 2001	Biotic index	/	Family	Rating : 0 - 13 5 Associated quality class
Biotic Index for San Luis Sierras (BISLS)	Argentina, 2017	Biotic index	/	Family, Genus	Rating: 1 - 12
Sierra of San Luis Macroinvertebrates Biotic Index (MBI)	Argentina, 2014	Biotic index	/	Family, Genus	Rating : 4 - 12
Saprobic Index for Brazilian Rivers in Minas Gerais and Rio de Janeiro states (ISMR)	Brazil, 2010	Biotic index	Sabropic valence, indication weight	Genus	Rating : 1 - 4

Table 6: Summary of other biological indices identified in Latin America and how they work

4.2.1. *Andean biotic index (ABI)*

Developed in 2014 by Blanca Ríos-Touma, Raúl Acosta and Narcís Prat, the ABI is a biotic index based on the BMWP scoring method. Adapting a specific index for the Andes was essential since this area, characterized by its high altitude, is home to species with characteristics different from the rest of the continent. They differ from lowlands because rivers have lower oxygen water contents, and the source of pollution is very different too. For example, organic pollution is lower but many rivers are polluted with mercury as a result of mining activities. Indeed, families are less abundant and the tolerance of several macroinvertebrate families to pollution differs from those of other regions (Ríos-Touma et al., 2014). It is therefore based on the same method as the BMWP, the final score obtained is equal to the sum of the scores associated with each taxon sampled. However, the authors have adapted the probability of presence of certain families and the pollution sensitivity scores to the Andean fauna. It was tested by the authors in Ecuador and Peru. The ABI is an integral part of the new multimetric index designed for high Andean fluxes (IMEERA) (Ríos-Touma et al., 2014).

In the end, the scores obtained are divided into 5 water quality classes whose boundaries are adapted according to the basin studied, for Peru and Ecuador, as follows: "class boundaries were defined at 61% (between moderate and good), 36% (between moderate and poor), and 15% (between poor and bad) of the 25th percentile of the index value at reference sites"(Ríos-Touma et al., 2014).

4.2.2. *Índice Multimétrico del Estado Ecológico para Rios Altoandinos (IMEERA)*

The IMEERA index or "Indice Multimétrico del Estado Ecologico para Rios Altoandinos" is a bioindication method using macroinvertebrates created at the scale of the Andes Cordillera in 2013 by Christian Villamarín, Maria Rieradevall, Michael J.Paul, Michael T.Barbour, Narcis Prat (Villamarín et al., 2013). This index is used to determine the ecological quality of high-altitude tropical rivers in the Andean regions (Table 7). This index is divided into two subparts; IMEERA-B and IMEERA-P, which are named according to a typical river: the B corresponding to Bosque and P to Paramo and Puna.

The first sub-index, IMEERA-B, corresponds to the lower altitude rivers for which degradation is mainly caused by a surplus of organic matter and changes in hydromorphology. This sub-index is based on macroinvertebrates as a function of stand richness, habitat characteristics and level of tolerance to disturbance, which are translated using the following 6 metrics: EPT taxa, % "clinger", % climbers, intolerant taxa, ABI and % tolerant taxa.

The second sub-index, IMEERA-P, is set up for higher altitude rivers where pressures and quality degradation are caused by organic pollution and habitat heterogeneity. This time, the calculation is based on only 4 metrics: total number of taxa, number of intolerant taxa, ABI and % of tolerant taxa. Contrary to the previous calculation, the habitat characteristics are not taken into account but only the richness of the stand and its tolerance to disturbance.

Class boundaries	Rating values	
	IMEERA B	IMEERA P
Very good	≥73	≥99
Good	72–43	98–73
Moderate	42–35	72–59
Poor	34–23	58–49
Poorest	<22	<48

Table 7: Quality classes associated with the values obtained after application of the IMEERA index - Villamarin et al., 2013

4.2.3. Biotic monitoring Patagonian streams (BMPS)

BMPS is a rapid water quality assessment protocol using macroinvertebrates. It was developed by Miserendino, ML, and Pizzolón, LA in 1999 for rivers in Patagonia.

Patagonia represents approximately 800,000 square kilometres, divided between Argentina and Chile. There are two distinct zones: a mountainous area and a plateau. Many of these river systems originate in the Andes and flow into the Pacific Ocean. They are fed by melting snow and precipitation. The other part drains the plateau to the Atlantic Ocean (Miserendino, 2001).
At the level of the mountain range, the altitude can exceed 3600 metres, rainfall can reach 3000 millimetres per year and the climate is classified as "cool temperate". For the rivers of the plateau, the altitudes are much lower, droughts are frequent with rainfall between 100 and 150 millimetres per year. There are four biozones in all; (1) AndeanHumid, (2) Sub-Andean Sub-humic, (3) Extra-Andean Eastern and (4) Extra-Andean Western (Miserendino, 2001). There are two phytogeographical provinces :"the Sub-Antarctic Forest and the Patagonian steppe. Perennial (Austrocedrus chilensis, Nothofagus dombeyi and Maitenus boaria), and deciduous species N.pumilio, N.antarctica) constitute the Sub-Antarctic forest. The deciduous tree locally named "lenga" (N.pulmonio) covers especially low order streams. Low watercourses are mainly flanked by Salix fragilis and S.nigra. Patagonian plateau shows an herbaceous-shrub-like steppe of several xerophytic forms : Mulimun spinosum, Stipa spp., Senecio spp., Colletia spinossisima, Adesmia sp., Fabiana imbricata and Poa sp." (Miserendino, and Pizzolón, 1999).As a result Patagonian rivers are home to many endemic species, so the authors support the need to create a specific index for this area.

BMPS is an adaptation of the BWMP. The result is given by a table listing 95 families of invertebrates and their pollution-sensitivity score from 0 to 10. The final score varies from 0 to 150 points (table 8). Like the BWMP, the principle is to sample the taxa and determine them by family, the final score will be the sum of the scores obtained by each sampled family (Miserendino and Pizzolón, 1999). It was later reused in several studies, in 2001 (Miserendino and Pizzolón, 2001), in 2008 (Miserendino et al., 2008) and in 2014 (Llallement et al., 2014) as a useful and efficient index for Patagonia.

Class	Value	Significance
I	150 150-101	Very clean water Unpolluted water
II	100-61	Probably incipient pollution or other kinds of perturbation
III	60-36	probably polluted water
IV	35-16	Polluted water
V	16-0	Strongly polluted water

Table 8: Water quality scale corresponding to water quality value - Miserendino and Pizzolon, 1999

4.2.4. Serra dos Órgãos Multimetric Index (SOMI)

This index was developed by Darcilio F. Baptista, Daniel F. Buss, Mariana Egler, Alexandre Giovanelli, Mariana P. Silveira & Jorge L. Nessimian in 2006 in the Serra dos Órgãos National Park in Rio de Janeiro State, Brazil. It is calculated using six metrics: Diptera percentage, Coleoptera percentage, taxonomic wealth (number of families, EPT Taxa, BMWP-CETEC and % Shredders). The quality classes are listed in Table 9. (Baptista et al., 2007).

Class	Poor	Regular	Good	Very Good
Scores	6 -12	13 - 18	19 -24	25 -30

Table 9: Quality classes for the SOMI index - Darcilio et al., 2006

Most macroinvertebrates need only be identified down to the family level, which simplifies the use of the index, with the exception of the orders Ephemeroptera, Plecoptera and Trichoptera and Shredders taxa, which must be identified at the genus level (Baptista et al., 2007). This method has the advantage of being easy and quick to apply, but the authors caution about the tendency to overestimate the water quality of sites with altered characteristics (deforestation, siltation) without chemical pollution (Baptista et al., 2007). The use of the index outside this region is not recommended due to differences in biological composition (Baptista et al., 2013).

4.2.5. Benthic Multimetric Index (BMI)

This index was developed in 2011 by Ferreira, WR.,Paiva, LT, and Callisto, M. to assess water quality in a Brazilian watershed del Rio das Velhas. It is very close to the SOMI index developed in 2006 by Baptista et al. since it is based on it. It has 6 metrics: taxonomic richness, percentage of Oligochaete, percentage of Chironomidae and Oligochaete (% CHOL), percentage of Ephemeroptera, Plecoptera and Trichoptera (% EPT), percentage of collector-gatherers, and BMWP-CETEC biotic index (Ferreira, 2011). The BMWP-CETEC is the index

developed by Junqueira et al. in 1998 which is an adaptation of the BMWP for Brazil (Junqueira et al., 1998).

Sampling is carried out 3 times per sampling site. Scores are assigned to each metric between 5 (reference state), 3 (intermediate state) and 1 (state furthest from the reference state). The sum of these six scores gives the final score between 6 and 30. Categories were established to reflect water quality (Table 10)(Baptista et al., 2007).

Value	6-12	13-18	19-24	25-30
Quality	poor	average	good	very good
Characteristics	waters with a high degree of impact, containing domestic sewage, low dissolved oxygen concentrations and degraded habitats, favouring the colonisation of tolerant organisms such as Oligochaeta and Chironomidae larvae	waters with a considerable degree of alteration, compromising the establishment of many pollution-sensitive benthic organisms	waters with low degree of alteration with good ecological characteristics	waters of excellent quality and ecological reference conditions

Table 10: BMI water quality categories - Baptista et al., 2007

Although developed for the Velhas watershed, this method can be used for other watersheds with similar characteristics (Ferreira, 2011).

4.2.6. Biotic Integrity Index using aquatic invertebrates (IBIAP)

This index was developed for Ecuador by Carrasco in 2008 for a Master's thesis (Holguin-Gonzalez et al., 2013). The IBIAP index is a multimetric index that uses the following four variables: taxonomic richness, the number of EPT taxa (mayflies, plecoptera and trichoptera), the number of filterers and shredders and the average pollution tolerance of the sample. The final result is between 0 and 16. High ecological quality water has an IBIAP value of 16, good quality water has a value between 12 and 15, moderate quality water has a value between 6 and 12 and poor quality water has a value below 6 (Holguin-Gonzalez, 2013).

4.2.7. *Indice Biotique Macroinvertébrés de Guyane (IBMG)*

This index has been developed to meet the objectives of the WFD, also applicable to the overseas territory. However, they have been somewhat neglected, and the first ecological assessment index for French Guiana appears late. It was developed in 2015 by N. Dedieu, S. Clavier, R. Vigouroux, P. Cerdan and R. Céréghino as the Biotic Macroinvertebrate Index for French Guiana (IBMG). For each site, samples are taken

(i) on organic substrates (A);
(ii) on mineral substrates (B).

IBMG is composed of six metrics: Chao1 (B), Log.Elmidae (A), Number of coleoptera (A + B), %collector-gatherer (A + B), %ephemeroptera and trichoptera (A + B) and the Shannon index (A + B). Most invertebrates are identified by family (except Annelida, Hydracarina, Nematoda and Planaria) (Dedieu et al., 2015).

Chao1 is an index for measuring biodiversity, it estimates the number of unobserved species from those observed once or twice. This is a minimum estimator: the expectation of the number of species is greater than or equal to the estimated number (Marcon, 2010).

IBMG is calculated using the formula (Dedieu et al., 2015):

$$IBMG = \frac{\sum DE_m \times EQR_m}{\sum DE_m}$$

Where DEm is the DE (discrimination efficiency) of metric m and EQRm the value of metric m.

According to the WFD, 5 ecological quality classes are established: "high" (from 1 to 0.69), "good" (from 0.69 to 0.51), "moderate" (from 0.51 to 0.45), "poor" (from 0.45 to 0.36) and "bad" (from 0.36 to 0) (Dedieu et al., 2015).

4.2.8. *Guapiaçu-Macau Multimetric Index (GMMI)*

This multimetric index is developed by the authors Oliveira, RB, Baptista, DF, Mugnai, R., Castro, CM, & Hughes, RM in 2011 et allows to determine the ecological quality of the wadeable streams present in the state of Rio de Janeiro, in the south of Brazil.
The nine metrics selected here following statistical tests are: family richness; Trichoptera family richness; Shannon family diversity; % Plecoptera individuals; % Ephemeroptera, Plecoptera and Trichoptera (EPT) individuals; % mollusk and Diptera individuals; % shredder individuals; proportion Chironomidae/Diptera individuals; and proportion Hydropsychidae/Trichoptera individuals. Identification is mostly done at the genus level, except for Diptera, Hemiptera and Lepidoptera which were identified at the family level.

This method makes it possible to obtain, by a rapid assessment of water quality, an index score that can vary between 0 and 100 and is divided into 5 water quality classes, each class being located 20 points apart (Table 11).

Red	Orange	Green	Light Blue	Dark Blue
Severely Impaired	Impaired	Intermediate	Good	Very good

0 20 40 60 80 100

Table 11: Delineation of water quality classes (Oliveira et al., 2011)

4.2.9. Piabanha-Paquequer-Preto Multimetric Index (PPPMI)

The PPPMI index is developed by the authors Darcilio F. Baptista; Roberta SG de Souza; Carla A. Vieira; Riccardo Mugnai; Ana S. Souza; Renata Bley S. de Oliveira in 2011, Brazil. This index, like the previous one, is a multimetric index, quick to implement. It also covers the state of Rio de Janeiro but focuses on a different watershed from the one mentioned in the previous article; the Piabanha-Paquequer-Preto basin. There are two authors common to both articles; Baptista DF and Oliveira RBS.

The PPPMI is based on six metrics: Family richness, Shannon-Wiener family diversity, EPT family richness, %Diptera, %MOLD (Mollusca + Diptera) and %Collectors. Of these six metrics, two describe the tolerance of taxa, three describe stand structure and one describes functions. Samples are taken, taking into account the heterogeneity of the habitats present on the study site. To do this, samples of 20m² of substrate are taken, respecting as far as possible the proportions of the dominant habitats present on the site. The identification of macroinvertebrates is mostly done at the genus level except for Diptera, Lepidoptera and Hemiptera which are identified at the family level.

The use of this index makes it possible to give the quality of the river according to five classes: Severely Impaired (values ranging from 0-20), Impaired (20-40), Fair (40-60), Good (60-80) and Excellent (80-100).

4.2.10. Biological Neotropical Low-land Stream Multimetric Index (NLSMI)

The Biological Neotropical Low-land Stream Multimetric Index is a multimetric index developed in the low-lying rivers of the Panama Canal watershed. Proposed in 2013 by two authors ; Julie E. Helson and D. Dudley Williams, it was successfully tested in 2016 for Ecuador (Damanik-Ambarita et al., 2016). It has seven metrics: % of scrapers (%SC), Margalef's index (taxa) (MI), ratio of Chironomidae/Diptera individuals (RCD), number of EPT (taxa) (EPT), % of Trichoptera (%T), % of shredders (%SH), and Shannon's evenness index (taxa) (SEI) and is calculated as follows (JE Helson and DD Williams, 2013) :

$$\mathrm{NLSMI} = 1.43(\mathrm{EPT} + \mathrm{MI} + \mathrm{SEI} + \%\mathrm{T} + \mathrm{RCD} + \%\mathrm{SC} + \%\mathrm{SH})$$

The Margalef index is calculated from the number of individuals sampled (N) and the number of species sampled (S) by the formula d = (S - 1) / ln(N).
The Shannon evenness index provides information on area composition and richness. It covers the number of different land cover types (m) observed along the straight line and their relative abundance (Pi). It is calculated by dividing the Shannon evenness index by its maximum (h (m)). It thus varies between 0 and 1 and is relatively easy to interpret.

SEI = SDI / max (SDI) = - ∑ (Pi * ln (Pi)) / ln (m).The final result of NLSMI, between 0 and 10, is classified according to 5 categories (table 12):

Reference	Good	Moderate	Poor	Bad
10-8	6-8	4-6	2-4	2-0

Table 12: NLMSI Quality Class Categories - Helson and Williams, 2013

The authors indicate that it is preferable to use the index during the dry season as it can be influenced by seasonal variations. Its use outside the Panama Canal watershed area should be tested to assess its universality (Helson and Williams, 2013). For a country neighboring Panama with a relatively similar climate, Ecuador, it has been shown that NLSMI works relatively well when applied to assess water quality in small rivers below 250 m above sea level, but does not work well for other types of rivers (Damanik-Ambarita et al., 2016).

4.2.11. Serra da Bocaina Multimetric Index (MISB)

The MISB was developed by Baptista, DF, Henriques-Oliveira, AL, Oliveira, RBS, Mugnai, R., Nessimian, JL, & Buss, DF in 2013 as a multimetric benthic index for the Serra da Bocaina bioregion in southeast Brazil. It is based on the SOMI index, as the primary goal of the study was to test the SOMI outside its region of creation (Serra dos Órgãos) which is located in the same ecoregion as the Serra da Bocaina. They found that the SOMI was not adapted to the Bocaina region and therefore adapted it to developing the MISB. The principle of the two indices is the same, only the metrics change. Six metrics integrate the MISB, including 3 that were already in the SOMI: taxonomic richness, trichoptera richness, %coleoptera,% diptera, IBE-IOC index, ratio EPT / Chironomidae. Most taxa should be identified at the family level (with the exception of Trichoptera at the genus level). Their study indicated the importance of testing biological indices before using them in new areas, even in the same ecoregion. The results of the index are shown in Table 13.

Class	Scores
Excellent	80-100
Good	60-79
Regular	40-59
Impaired	20-39
Severely impaired	0-19

Table 13: The MISB classification system, divided in five classes of environmental stream quality - Baptista et al., 2013

4.2.12. Trophic State Index for Benthic Invertebrates (TSI-BI)

The TSI-BI is being developed for the rivers of Uruguay, more specifically in the Santa Lucia basin in 2011, by Guillermo Chalar, Rafael Arocena, Juan Pablo Pacheco and Daniel Fabián. This is the first index that proposes a classification of trophic states for South American rivers (Chalar et al., 2011). Its principle is quite similar to that of the ICE: it combines a direct gradient analysis (CCA) based on the benthic invertebrate abundance matrix and an environmental

variable matrix, with a weighted average (WA) model that is used to estimate the optimum and tolerance of each taxon. The optimum is the numerical score of each genus indicating its ecological "optimum" on the natural water gradient, while the tolerance corresponds to its ecological valence and is therefore used to weight the optimum. The system trophy is then found by combining the TSI-BI score with the total phosphorus (TP) content described in Table 14. (Chalar et al., 2011).

	Group 1 Mesotrophic	Group 2 Eutrophic	Group 3 Hypereutrophic
TP (μg/l)	<71	71–383	>383
TSI-BI	>8	8–6	<6

Table 14: Representation of trophic groups according to TP and TSI-BI values - Chalar et al., 2011

Once optimal and tolerance scores are estimated, the use of TSI-BI is very simple and quick and should be integrated into national monitoring programs (Chalar et al., 2011). It was used later in 2012 to assess the trophic status of waters in other basins, the Paso Severino basin (Uruguay) (Pacheco et al., 2012) and in 2015 for the waters of the "Esteros de Farrapos" National Park (Bazzoni, 2015).

4.2.13. Ecological quality index (ICE)

This index is being developed as an alternative to the BMWP-Col index, which is widely used in Colombia (Roldán, 2003), but some criticisms have been levelled at its country-wide adaptability and accuracy (Forero, L. C et al., 2014). It is for these reasons that 4 authors (Laura Cristina Forero, Magnolia Long, John Jairo Ramírez R. & Guillermo Chalar) developed the ICE in 2014. It is based on physico-chemical variables (total phosphorus TP and water temperature) and macroinvertebrate abundance and tolerance. The calculation of the index is based on an environmental gradient developed by the authors using the CCA (Canonical Correspondence Analysis) method and on the weighted average (WA) model used to calculate the tolerance of taxa to pollution. Each genus is associated with a tolerance and ecological optimum score that gives an ICE_{RN-MAE} score. Water quality is then determined using the ICE_{RN-MAE} score and total phosphorus in micrograms/litre classified into 3 categories of ecological status: good (group 3), regular (group 2) and critical (group 1) as shown in table 15 (Forero et al., 2014).

	Grupo 1	Grupo 2	Grupo 3
Calidad ecológica	Crítica	Regular	Buena
Fósforo total (μg/l)	>246	111-246	<111
ICE_{RN-MAE}	≤4.9	5-6	>6.1

Table 15: Threshold values for total phosphorus and ICE defining the quality class - Forero et al., 2014

The ICE is considered more precise and objective than the BMWP by the authors since each taxon is determined by genus or species and each abundance is taken into account. It therefore requires more time and more experienced assessors (Forero et al., 2014).

4.2.14. Yungas Biotic Index based on 4 taxa (IBY-4)

IBY-4 is a biotic index developed in 2011 by DA Dos Santos, C. Molineri, MC Reynaga and C. Basualdo in 2011 for rivers in the tropical Andes. It explains the presence of Elmidae, plecoptera, trichoptera and megaloptera. The IBY-4 result is classified as five discrete states {0, 1, 2, 3, 4}. IBY-4 = 0 means that none of the four taxa was detected along the sampling site, IBY-4 = 1 means that only one of the four taxa was recorded, and so on. These four taxa were selected because they are present in Andean river communities and represent easily recognizable taxonomic levels. This makes them a practical tool to assess river quality in the field even for non-experts (Dos Santos et al., 2011).

4.2.15. Biotic Index for PAMPean rivers and streams (IBPAMP)

The IBPAMP index was developed in Argentina in 2001 by 3 researchers: Alberto Rodrigues Capıtulo, Mariana Tangorraa and Carolina Ocon in order to assess the quality of the aquatic environments of "la Pampa", a region of South America comprising part of Argentina, Uruguay, and half of the state "Rio Grande do Sul" in Brazil (Alberto Rodrigues et al., 2001). The rivers in this region are semi-permanent, i.e. the water is only temporarily present due to the semi-desert character of the area.

IBPAMP is a water quality assessment method belonging to the group of biotic indices. These methods require an inventory of the macroinvertebrates present on the site as well as a standard double-entry table; on one side are the macroinvertebrates identified at the order, family or genus level according to the method and on the other side are the number of individuals. The next step is to identify the category appearing first in the table and then look at the number of individuals present. The result is a score that reveals the quality of the environment.

In the case of IBPAMP, there are 7 groups of macroinvertebrates, identified at the family or order level and grouped in two tables (Table 16 and Table 17) depending on whether the river is in a rithral or a potamal zone. The scores obtained range from 0 to 13, with 0 being the least good and 13 the best, and are divided into five water quality classes.

Faunistic groups			Total numbers of systematic units present						
			0–1	2–5	6–10	11–15	16–20	21–25	>26
			Biotic index						
1	Trichoptera with cases	> 1 S. U.	–	–	9	10	11	12	13
	(Leptoceridae)	Only 1 S.U.	–	–	8	9	10	11	12
2	Other Trichoptera Lestidae,	> 1 S. U.	–	6	7	8	9	10	11
	Elmidae, Gomphidae, Unionidae	Only 1 S.U.	–	5	6	7	8	9	10
3	Ancylidae, Decapoda,	> 1 S. U.	–	4	5	6	7	8	9
	Aeshnidae, Simuliidae	Only 1 S.U.	–	3	4	5	6	7	8
4	Other Coleoptera Ephemeroptera (Caenidae excepted), Libellulidae	All S.U. above absent	–	3	4	5	6	7	–
5	Coenagrionidae, Caenidae, Heteroptera, Amphipoda	All S.U. above absent		2	3	4	5		
6	Tubificidae, red Chironomidae, Physidae, Culicidae	All S.U. above absent	1	1	2	3			
7	Syrphidae, Enchitreidae, Psychodidae	All S.U. above absent	–	0	1	2			

Table 16: Standard table for the calculation of the IBPAMP index - Potamal zone - Alberto Rodrigues et al., 2001

Faunistic groups			Total numbers of systematic units present						
			0–1	2–5	6–10	11–15	16–20	21–25	>26
			Biotic index						
1	Trichoptera with cases	> 1 S. U.	–	–	8	9	10	11	12
	(Leptoceridae)	Only 1 S.U.	–	–	7	8	9	10	11
2	Hydropsychidae Lestidae,	> 1 S. U.	–	6	7	8	9	10	11
	Elmidae, Gomphidae	Only 1 S.U.	–	5	6	7	8	9	10
3	Ancylidae, Decapoda,	> 1 S. U.	–	4	5	6	7	8	9
	Aeshnidae, Simuliidae, Other Trichoptera	Only 1 S.U.	–	3	4	5	6	7	8
4	Other Coleoptera Ephemeroptera (Caenidae excepted)	All S.U. above absent	–	3	4	5	6	7	–
5	Coenagrionidae, Caenidae, Heteroptera, Amphipoda	All S.U. above absent		2	3	4	5		
6	Tubificidae, red Chironomidae, Physidae, Culicidae	All S.U. above absent	1	1	2	3			
7	Syrphidae, Enchitreidae, Psychodidae	All S.U. above absent	–	0	1	2			

Table 17: Standard table for the calculation of the IBPAMP index - Rhitral zone - Alberto Rodrigues et al., 2001

4.2.16. Sierra of San Luis Macroinvertebrates Biotic Index (MBI) and Biotic Index for San Luis Sierras (BISLS)

These two biotic indices will be implemented in Argentina in 2014 and 2017 by two teams of researchers with four researchers in common. These two methods are biotic indices based on the work of Vallania, Garelis, Trípole and Gil, from 1996.

Both biotic indices use the taxonomic richness as well as the sensitivity of taxa to determine index scores and identification is by genus or family (Vallania et al., 1996). For the MBI the results range from 4 to 12 for highly contaminated to uncontaminated environments, while for the BISLS they range from 1 to 12 for contaminated to uncontaminated environments.

Conclusion

This state of the art concerning the progress of bioindication by macroinvertebrates in Latin America shows that there is a growing awareness of the need to assess water quality.

Even if the pioneer countries of these methods are still the United States and European countries, a research effort is currently being made to fill the lack of knowledge regarding the sensitivity of the different Latin American taxa to pollution. It is becoming possible to begin to adapt the foreign method to the ecology of Latin America.

Thus, even though 32% of countries continue to directly apply these foreign methods and there are still four countries that do not yet use macroinvertebrate bioindication methods, it is possible to see that 73% of countries have started to develop their own methods. The number of methods used in Latin America thus varies between 0 and 11 depending on the country. Several of them, such as Ecuador, Brazil, Argentina and Colombia are very invested in research.

A research effort has therefore been carried out in Latin America since the early 2000s and continues to fill the knowledge gap concerning macroinvertebrates with the aim of continuing to develop methods specific to these countries with their rich and specific aquatic ecology.

Part 2 - Mexico study case

1. General context : bioindication in Mexico

1.1. The Mexican territory

There are 18 megadiverse countries in the world that hold two thirds, or even three quarters, of all biodiversity (Mittermeier et al., 2008). Mexico is one of them and ranks fourth in the world in terms of biological diversity. This biological richness can be explained by the fact that Mexico's surface area (1.973 million km²) is greater than the average surface area of Central American countries in general. Mexico also has a very high climatic and geomorphological variability. The north of the country is arid or semi-arid with an average annual rainfall of less than 500 millimeters. In comparison, the south of the country is humid with an average annual rainfall of 2000 millimeters (CONAGUA, 2016). There are therefore 11 biogeographic regions divided into arid, semi-arid, temperate and humid zones. It is also located in the transition zone between two of the eight biogeographic regions of the planet: the Nearctic and Neotropic regions (Alonso-Eguía-Lis et al., 2014). The 13 administrative hydrographic regions that serve as the basic unit for water resource management have been defined by The National Water Commission (CONAGUA), the administration responsible for freshwater management in Mexico (CONAGUA, 2016) (Figure 4). Mexico has a large number of rivers forming a 633,000 kilometer long river system (Figure 5).

Figure 4: Administrative hydrographic regions of Mexico. Source: CONAGUA, Atlas del agua, 2016.

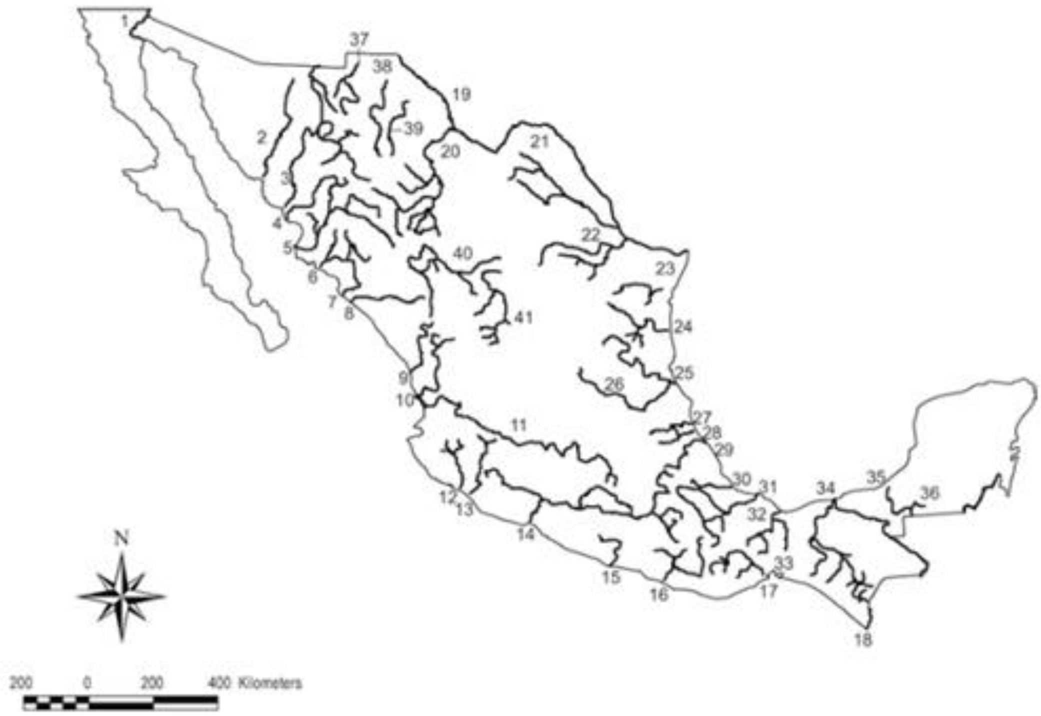

Figure 5: 41 major rivers in Mexico. Source: Mexican Aquatic Environments, Ibáñez, 2019 .

Legend: Main rivers in Mexico : 1 Colorado, 2 Sonora, 3 Yaqui, 4 Mayo, 5 Fuerte, 6 Sinaloa, 7 Culiacán, 8 San Lorenzo, 9 Acaponeta, 10 San Pedro, 11 Lerma-Santiago, 12 Armería, 13 Coahuayana, 14 Balsas, 15. Papagayo, 16 Verde, 17 Tehuantepec, 18 Suchiate, 19 Bravo or Grande, 20 Conchos, 21 Salado, 22 Pesquería, 23 San Fernando, 24 Soto La Marina, 25 Tamesí, 26 Pánuco, 27 Tuxpan, 28 Cazones, 29 Tecolutla, 30 Jamapa, 31 Papaloapan, 32 Coatzacoalcos, 33 Uxpanapa, 34 Grijalva, 35 Usumacinta, 36 Candelaria, 37 Casas Grandes, 38 Santa María, 39 Del Carmen, 40 Nazas, 41 Aguanaval (Ibáñez, 2019)

However, the country faces many environmental problems, such as air and water pollution, urbanization, deforestation, invasive alien species, climate change, which cause the risk of extinction of about 2600 species (Ibáñez, 2019).

In addition, very little knowledge has been acquired about its biodiversity, especially its freshwater macroinvertebrate populations. Indeed, studies have mainly focused on plant and fish species (Miller et al. 2005), but more and more recent studies are attempting to gain knowledge on invertebrate taxa, both terrestrial and aquatic. The National Commission for the Knowledge and Use of Biodiversity (CONABIO) initiated a program in 1997 to locate Priority Hydrological Regions in Mexico, the RHP (Regiones Hidrológicas Prioritarias) program (figure 6).

The purpose of this program is to locate priority limnological regions where conservation actions need to be carried out. 110 RHPs have been defined for their high biological value. Approximately 26.4% of them are selected because of a significant lack of scientific knowledge regarding their biodiversity (Ibáñez, 2019). However, very little data on entomofauna are collected during this project (Alonso-Eguía-Lis et al., 2014).

To remedy this, a project was developed in 2004 following Mexico's participation in COP-7.

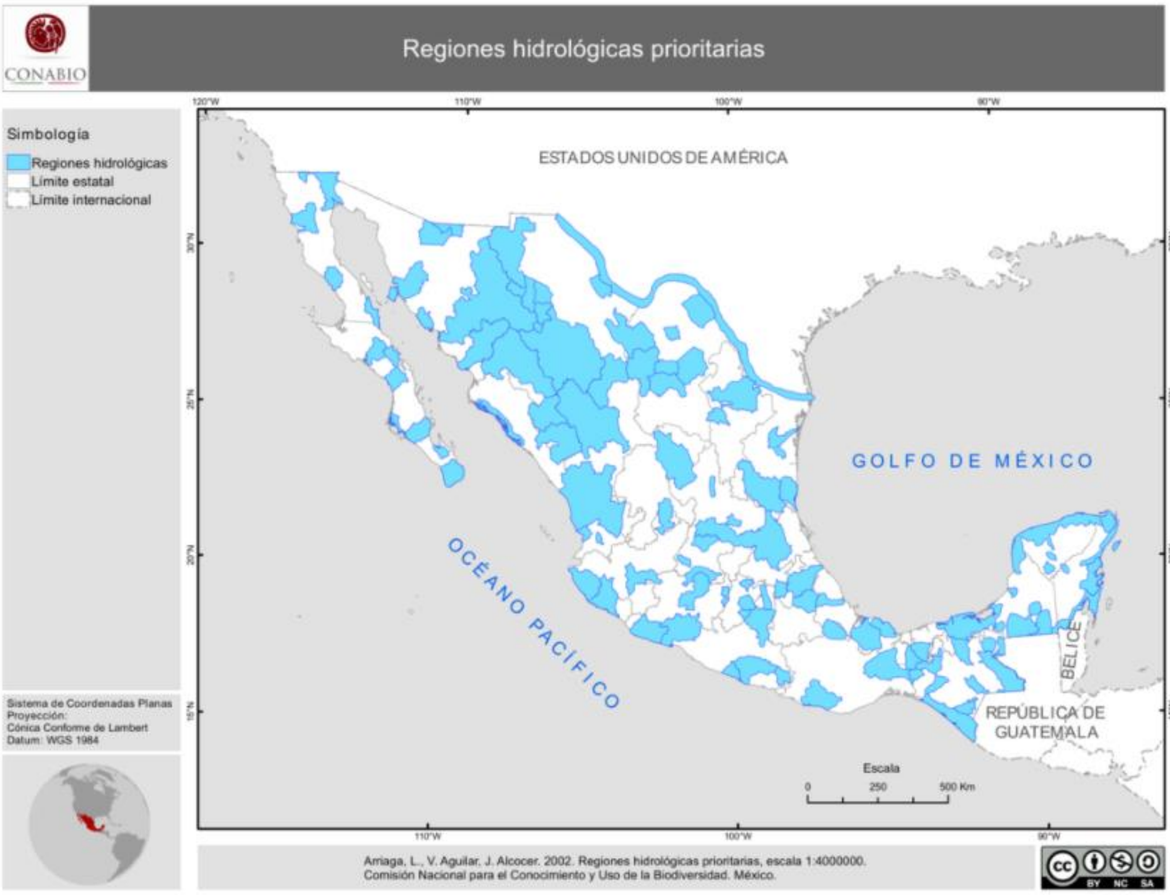

Figure 6: Priority Hydrological Regions in Mexico (Arriaga and al., 2002)

This program, called the Program of Work on Protected Areas, aims, among other things, to fill these gaps, specifically targeting rivers, water bodies and wetlands (Alonso-Eguía Lis et al., 2014).

1.2. Water Quality Assessment in Mexico

Currently, water quality assessment in Mexico is carried out using physico-chemical quality data collected by CONAGUA since 2005. It is carried out through three indicators: five-day biochemical oxygen demand (BOD5), chemical oxygen demand (COD) and total suspended solids (TSS) (Alonso-Eguía-Lis et al., 2014). The monitoring network consists of 4,999 stations distributed across the country between groundwater, surface and coastal waters. 2,709 stations are dedicated to surface water assessment (CONAGUA, 2016).

The DBO5 is the biochemical oxygen demand for 5 days, it measures the amount of biodegradable organic matter contained in water. This biodegradable organic matter is evaluated through the oxygen consumed by the microorganisms involved in the natural

purification mechanisms. The majority (55.6%) of the plants are considered to be of excellent quality (figure 7). The majority of polluted or heavily polluted plants are located in the central part of the country, which is the most urbanized and densely populated, together with Mexico City (8.855 million inhabitants in 2015) (figure 8).

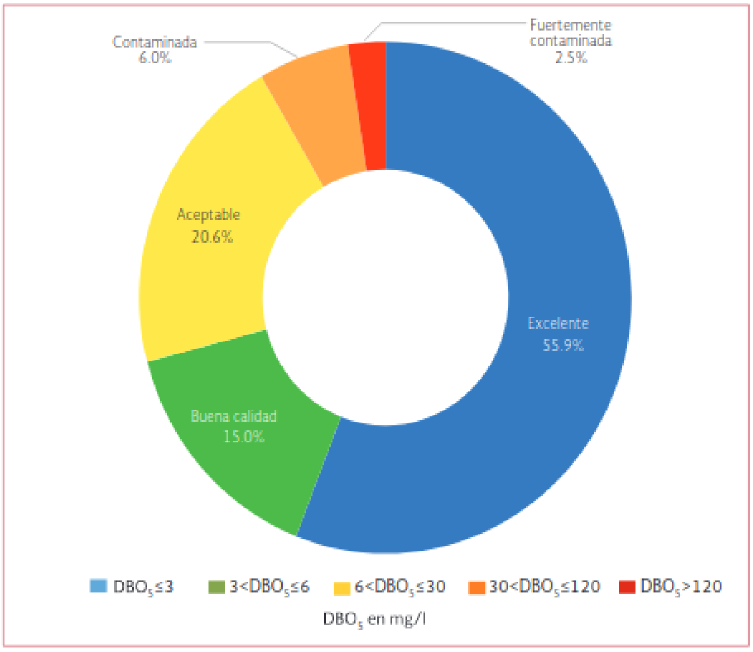

Figure 7: Percentage distribution of sites evaluated according to DBO5. Source: CONAGUA (2016)

Figure 8 : Map of sites evaluated according to DBO5. Source: CONAGUA (2016)

Chemical Oxygen Demand, or DCO, is the amount of oxygen needed to oxidize all the organic matter contained in water. Only 20% of the sites are considered excellent, and about 30% of the sites are polluted or very polluted (figure 9). For this parameter, the most polluted sites are also found in the most urbanized areas of the country (figure 10).

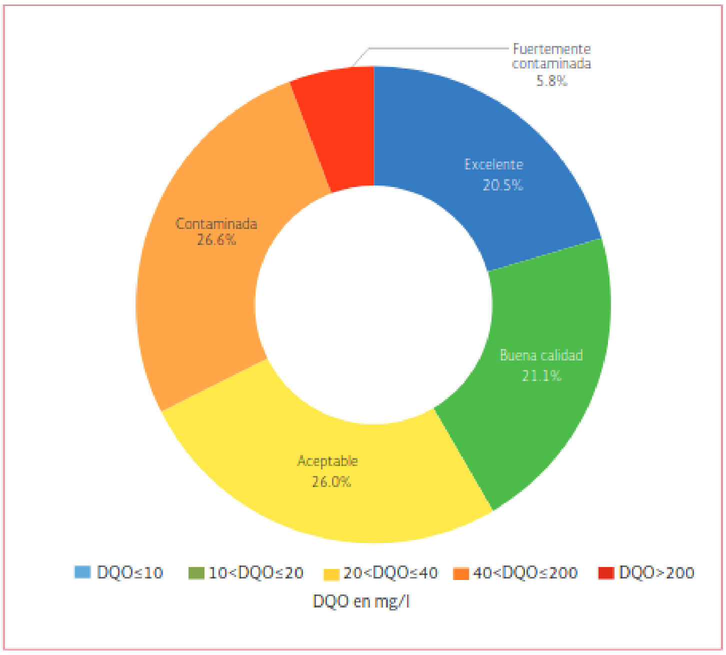

Figure 9: Percentage distribution of sites evaluated according to COD. Source: CONAGUA (2016)

Figure 10: Map of sites evaluated according to COD. Source: CONAGUA (2016)

Concerning Total Suspended Solids (TSS), most of the country is in acceptable conditions or above (figure 11). The stations whose quality is considered poor or very poor are mainly in the agricultural areas of the country (figure 12).

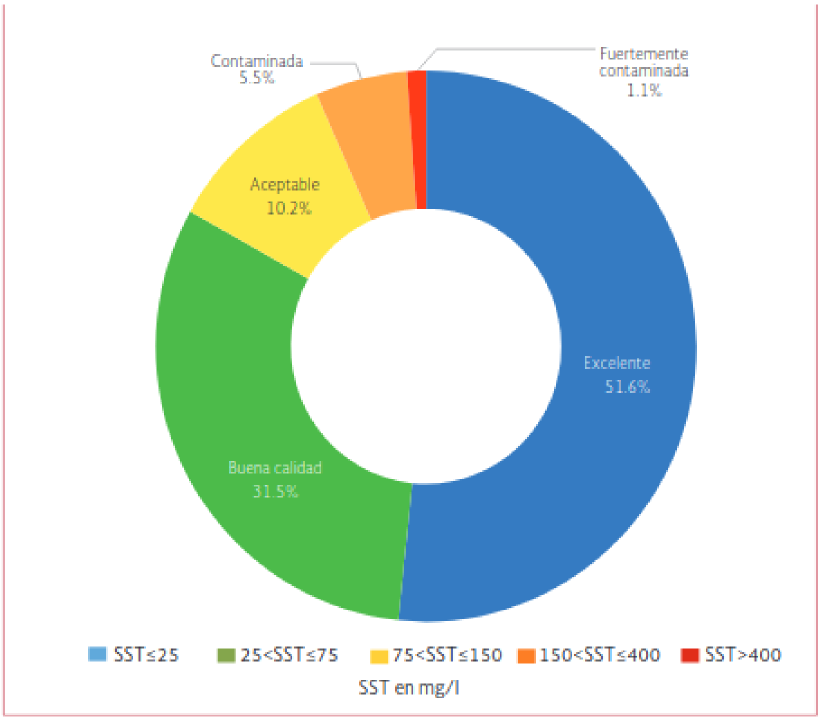

Figure 11: Percentage distribution of sites evaluated according to TSS. Source: CONAGUA (2016)

Figure 12: Map of sites evaluated according to TSS. Source: CONAGUA (2016)

1.3. Bioindication in Mexico

Bioindication for water quality assessment is still rarely used in Mexico (Henne, Schneider y Martínez, 2002), in contrast to other Central American countries as we saw in Part I, such as Costa Rica, Brazil, Ecuador and Argentina.

The application of biotic indices in Mexico is limited to cases such as those of Rosas-Acevedo and collaborators in 2013, López-Hernández, Ramos-Espinosa and Carranza-Fraser in 2007, Brain and collaborators in 2002, or that of Henne, Schneider and Martínez in 2002 (Padilla-González CM and al., 2016).

The methodologies for assessing water quality using macroinvertebrates are mainly of two types. First, there are European methods (based on a scoring method) such as BMWP and IBE. Second, biotic index methods, with the principle of biotic integrity using metrics based on community structure and habitat conditions, which began with IBI and led to the development of other indices such as IBIAMA.

The National Water Commission, the Mexican Institute of Water Technology (IMTA) and the Biology Faculty of the University of Michoacana of San Nicolás are collaborating in the creation of a specialized bioindication center, where work is underway to propose a biomonitoring protocol. In 2008, IMTA is developing a procedure for water quality assessment by macroinvertebrates that provides a method that complies with quality standards (Alonso-Eguía-Lis et al., 2014).

2. Bioindication methods currently being developed in Mexico

2.1. Global Water Watch Mexico

The Global Water Watch programme (GWW, http://www.globalwaterwatch.org/) was set up by Auburn University in the United States in 1992 (Flores-Díaz et al., 2013). It is a community-based water quality monitoring programme based on voluntary citizen participation. Methods that are sufficiently simple and applicable without too many technical constraints are developed to be applied in the field, after training, by non-professionals. The aim here is not only to create volunteer manpower to acquire field data, but to involve citizens in river management. They are therefore ultimately responsible for collecting, interpreting and communicating the results (Ramos-Escobedo, 2016).

There are specific organisations as well as groups of voluntary citizens based in the member countries of the programme. In Mexico, it is GWW-Mexico which, since 2005, has been forming groups of volunteer citizens called "Organizaciones de la Sociedad Civil" (OSC). By 2013, there were already 45 such groups in 12 of the 32 states of the republic, representing more than 750 volunteers (Flores-Díaz et al., 2013).

In order to monitor water quality, five modules are implemented: Water chemistry monitoring, Bacteriological monitoring, Stream biomonitoring, total suspended solids monitoring and stream discharge monitoring. In this EFP, we will focus solely on stream biomonitoring, which is based on the use of macroinvertebrates.

As the methods are applied by citizens, the resolution of the techniques used is lower than that of standard methods. Data Quality Assurance Plans (PACD) are set up by the GWW programme and are validated by the US Environmental Protection Agency (EPA) and declared effective enough to set up an early warning system (Ramos-Escobedo, 2016). On the other hand, this system frequently provides data, as most groups carry out monthly monitoring of basic characteristics (Flores-Díaz et al., 2013).

Citizen training and certification workshops are carried out at the request of a community or group. The training consists of a theoretical part that allows them to better understand the functioning of the rivers and especially the one they will be working on. There are also practical sessions in which volunteers go out into the field individually, accompanied by a certified trainer. There is also re-certification, which takes place one year after the first one in order to review, correct techniques and eliminate doubts (Flores-Díaz et al., 2013).

The workshops are partly based on the use of the board game "BIO-ASSESS", developed in 1993 by the University of Auburn (http://www.globalwaterwatch.org/what-we-do/methods/biomonitoring/). The use of this game enables participants to learn to identify and learn about the ecology of common macroinvertebrates, as well as to calculate a biological index and obtain a result in terms of water quality. This result is then interpreted according to the human activities present in the catchment area. Usually, the sampling of the game, which is the basis of the interpretation exercise, is carried out by random sampling of 100 macroinvertebrate maps. In the case of the GWW training, the participants carry out a real sampling in the river to obtain the sample.

The groups of volunteers take a manual sample from each site using a 1 mm mesh aquatic net (kick-net or D-net) (Campbell, 2007). In order to collect macroinvertebrates, the sediment present in front of the net is stirred and cleaned by hand. Between 100 and 200 insects are then sorted and the rest of the sample is placed in 96% ethanol for preservation. Sorting is carried out using tweezers and a simple photographic key. The macroinvertebrates are placed in white plastic bins and sorted into three sub-categories (Table 18) according to their pollution tolerance. The different types of macroinvertebrates are then counted to determine their abundance in the sample (> 10: abundant, 4-9: common, 1-3: rare). The number of individuals in each category is then summed and multiplied by a factor to determine the water quality of the river (Campbell, 2007) (Table 19).

Category 1	Category 2	Category 3
Intolerant to pollution	Partially tolerant to pollution	Tolerant to pollution
mayflies, stoneflies, caddisflies not from the family Hydropsychidae, riffle beetles, water penny beetles : family Psephenidae, aquatic snails	hellgrammites, dragonflies, craneflies, filtering caddisflies from the family Hydropsychidae, crayfish, amphipods, isopods, snipeflies, blackflies	worms, midges, air-breathing snail

Table 18: Macroinvertebrate subgroups - Campbell, 2007

Calculation	Number of individuals in category 1 * 3 + Number of individuals in category 2 * 2 + Number of individuals in category 3 * 1			
Result	> 22	17 - 22	11-16	< 11
Water quality	Excellent	Good	Fair	Poor

Table 19: Water quality - Calculation method and interpretation of results - Campbell, 2007

2.2. Method developed by the Mexican Institute of Water Technologies (IMTA)

Since 2008, the Mexican Institute of Water Technologies or Instituto Mexicano de Tecnología del Agua (IMTA) has been developing a procedure for assessing water quality via macroinvertebrates: "Evaluación de la calidad del agua a través de macroinvertebrados (índices de diversidad e índice biótico)". This methodology is based on the use of the diversity indices of Shannon-Wiener (H') and Brillouin (HB) and the Hilsenhoff biotic index (Alonso-Eguía-Lis, Ramirez Melchor, 2017).

With regard to the field protocol, the sampling areas should be approximately 100 metres long and be representative of the diversity of the river's microhabitats. If possible, they should be located more than 100 metres from any bridge, dam or other obstacles that could have an impact on the speed, depth of water and ultimately the quality of the habitat (Alonso-Eguía-

Lis, Ramirez Melchor, 2017). Each sampling station is the subject of a precise field sheet (Annex 2) which provides information on the following points:

- the climatic conditions on the sampling date
- the location of the site (site diagram, photographs, if possible GPS point: altitude, longitude, latitude
- the characteristics of the watercourse (type of watercourse, origin, length, average depth, size of the catchment area etc.).
- the characteristics of the water (temperature, conductivity, pH etc.)
- characteristics of the water input (soil type, contamination, local erosion)
- the type of riparian and aquatic vegetation
- the types of habitats present (in percentages)
- the organic and inorganic components of the substrate (in percentage)

The number of samples taken varies according to the rivers in order to obtain a panel of macroinvertebrates representative of the environment. Indeed, it should be taken into account that all rivers have a great diversity of microhabitats and that their attractiveness to macroinvertebrates varies. It is therefore necessary to sample areas with a high concentration of individuals, on different substrates and by varying parameters such as vegetation (presence, absence, submerged, emerged). It is therefore recommended to carry out, from downstream to upstream, between 3 and 6 samples of one square meter distributed among:

- river banks where sand is found with or without vegetation,
- slow flow areas where gravel with or without vegetation is found,
- fast flowing areas where rocks or mixtures of gravel and rock are found.

Samples are stored in a jar labelled with 96% ethanol. Macroinvertebrates are identified at the taxonomic level of the family, in the laboratory, using a stereo microscope (Alonso-Eguía-Lis, Ramirez Melchor, 2017). Macroinvertebrates belonging to the same family are brought together in a single jar. The total and relative densities and the Shannon-Wiener, Brillouin and Hilsenhoff indices (Table 20) are calculated for each family.

Table 20: Different indices calculated on the taxonomic list of macroinvertebrates resulting from the harvest

Indice	Equation	Members of the equation
Shannon-Wiener Diversity Index	$H' = -\sum Pi \times \ln(Pi)$	Pi = the relative density of each family Pi = ni/N with neither the number of individuals per family and N the total number of individuals
Brillouin Diversity Index	$HB = \frac{\ln N! - \sum \ln(ni!)}{N}$	N = total abundance ni = abundance per family
Hilsenhoff biotic index	$IHB = \frac{\sum nj \times aj}{N}$	nj = abundance of each taxon (family) aj = pollution tolerance value associated with nj N = total number of individuals

The application of the Hilsenhoff (1987) biotic index provides information on water quality (Table 21), while the other indices can be used for multiple statistical analyses of the MVSP (Multivariate Statistic Package) type (Alonso-Eguía-Lis, Ramirez Melchor, 2017).

IHB value	Water quality	Level of organic contamination
0.0 – 3.5	Excellent	No apparent organic pollution
3.51 – 4.5	Very good	Possible slight organic pollution
4.51 – 5.5	Good	Some organic pollution
5.51 – 6.5	Fair	Fairly significant organic pollution
6.51 – 7.5	Fair poor	Significant organic pollution
7.51 – 8.5	Poor	Very significant organic pollution
8.51 – 10.0	Very poor	Severe organic pollution

Table 21: Correspondence between BHI values and water quality - Source: Hilsenhoff (1987)

2.3. Comparison and assessment of the methods used

As noted above, two methods based wholly or partly on macroinvertebrates are currently used in Mexico to determine water quality (Table 22). Each of these methods has advantages, disadvantages and limitations, as we shall see.

The method developed by GWW-Mexico, which, as a reminder, is based on voluntary work by citizens, has the advantage of being a method for acquiring a lot of data. These data are then made available to the scientific community and are used to draw up river management plans.

Field visits and sampling are carried out regularly, sometimes even monthly (Campbell, 2007). Moreover, the method is quick and simple to implement. However, we did not find any documentation describing precisely the field sampling method and it would appear that the sampling area is determined fairly randomly. Only one sample seems to be taken per site. It should also be taken into account that it is citizens, a priori non-scientists, who carry out these operations. Thus, even if the operators are trained in the field, their ability to determine an adequate and representative sampling zone for the river sampled seems to be less than that

of professional operators. The same observation can be made for identification, which is based on the use of simple photographic keys.

The method set up by the IMTA, on the other hand, is based on a precise and detailed sampling protocol. Similarly, the identification of macroinvertebrates is carried out at family level, which is more precise than for the previous method. This method is therefore less easily applicable and requires much more time to carry out, especially for the laboratory determination phase, than the GWW-Mexico method.

Please note, however, that little documentation concerning the description of the GWW-Mexico method could be found. On the contrary, the method developed by the IMTA is described very precisely. This factor may influence the fact that the IMTA field method seems here much more precise than the GWW-Mexico method, which appears to be highly simplified.

It should also be noted that the determination of water quality proposed by the IMTA is based on the use of the Hilsenhoff biotic index developed in 1987. This calculation method uses a pollution tolerance coefficient associated with different taxonomic levels in macroinvertebrates. However, these initial tolerance values are mainly based on the study of 53 rivers in Wisconsin, USA (Hilsenhoff, 1987). During this study, the physical and chemical parameters of the rivers were studied in order to determine the degree of organic and nutrient pollution. Macroinvertebrate samples from these same rivers were then used to associate species with degrees of sensitivity to pollution (Hilsenhoff, 1987).

However, as explained in the general context, Mexico is a megadiverse country. It is therefore questionable whether the pollution tolerance values developed in the United States can be applied to Mexico.

Method	Criteria analysed	Difficulty in the field	Difficulty in the laboratory	Method of transforming results into index value	Quality of the evaluation (robustness, replicability)	Weaknesses of the method
Global Water Watch Mexico	5 criteria: chemistry, bacteriology, bioindication by macroinvertebrates, suspended matter, solid transport	1 manual sampling per site with a 1 mm mesh net (kick or D-net)	Visual sorting (simple photographic key) Sorting into 3 categories: pollution intolerant / somewhat tolerant / tolerant (Table 17)	Number of individuals in category 1 * 3 + Number of individuals in category 2 * 2 + Number of individuals in category 3 * 1	Easy to set up protocol.	Highly simplified method. Carried out by non-scientists: misclassification or oversights, especially for small individuals.
IMTA	Diversity indices: Shannon-Wiener (H') and Brillouin (HB) Hilsenhoff biotic index.	3 to 6 samples of $1m^2$ depending on the conditions of the watercourse and the habitat diversity present	Sorting under a stereo microscope. Identification at the taxonomic level of the family	Hilsenhoff Biotic Index (1987) : $IHB = \frac{\sum nj \times aj}{N}$	GPS points and photographic reporting make it easy to find the stations from one year to the next.	Do the pollution tolerance values (1987) correspond to the ecology of macroinvertebrates in Mexico?

Table 22: Summary of the two main methods used in Mexico

3. Proposal of a method for the assessment of water quality via macroinvertebrates in Mexico

3.1. Collection of information

In order to be able to propose a water quality assessment method based on macroinvertebrates in Mexico, expert opinion on the subject is collected via a twelve-question questionnaire (Annex 3) circulated in Mexico by Ms Kolb Melanie, Professor of Geography, UNAM.

Part of this questionnaire provides information on the previous experiences of researchers in relation to bioindication via macroinvertebrates, the main results, what they thought of their effectiveness or what type of method they consider the most suitable. This part should enable us to identify the type of preferential index to be developed.

The rest of the questionnaire allows us to gather the scientists' opinion on whether or not it is necessary to define a bioindication method specific to regions of Mexico. It also enables the opinion of the respondents to be gathered on the need to carry out more fundamental research to better understand the pollution-sensitivity of species living in Mexican rivers. This part should enable us to take stock of the knowledge already acquired and that which remains to be developed in order to identify the different steps needed to create the water quality assessment index.

The last two questions open up the possibility of not only developing an index for Mexico, but also to carry it out in collaboration with and for other Latin American countries.

3.2. The main results

After Ms. Kolb Melanie sent out a questionnaire in Mexico, we received 7 responses. Concerning the profile of the 7 respondents, 4 of them are researchers in science, aquatic ecology, river ecosystem or more generally in environment with an aquatic speciality. There is also one doctoral student. Two respondents are technicians; university or for a basin organisation (figure 13). Most of them (5 people out of 7, i.e. approximately 72%) have experience with bioindication by macroinvertebrates.

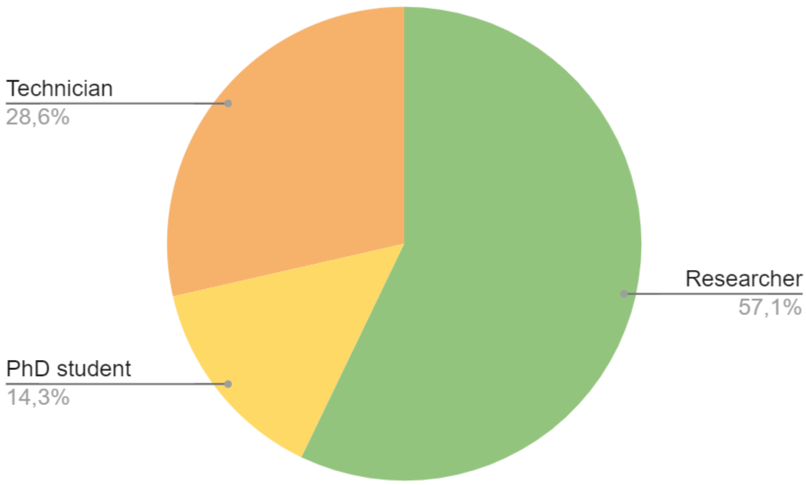

Figure 13: profile of respondents

3.2.1. Preferred types of methods

Respondents were asked to give their opinion on what type of method they thought would be most suitable for achieving bioindication by macroinvertebrates in Mexico. They were then asked to indicate the advantages of each type of method that justified their choice.

The "scoring method" type is most often mentioned by respondents, with 4 out of 7 responses including this type of method (Figure 14). More specifically, responses include the Biological Monitoring Working Party (BWMP) (4 out of 4 people) and the Family Biotic Index (FBI) (1 out of 4 people). According to the respondents, the advantages of these methods are that they are simple to implement, especially as identification is only done at the family level, making them simple and quick methods.

The multimetric index type was chosen by 3 people (figure 14). It includes the Biotic Integrity Index (IBI), mentioned by one person for its low cost. The other two respondents indicate that multimetric indices are advantageous because they are able to integrate all the complexity of the system. In addition, one person indicated that he was against the use of the BMWP because, in his opinion, the presence-absence analysis is too simple and does not allow a good representation of the system.

The biotic index type was mentioned by two people (figure 14), the indices in question are not specified. According to one person, biotic indices are more suitable because they use functional and non-taxonomic groups, which have the disadvantage of being poorly calibrated in terms of pollution-sensitivity and giving results that are not consistent with the quality of the environment.

One person mentioned the EPT index (Ephemeroptera, Plecoptera and Trichoptera) and the EPTO index (Ephemeroptera, Plecoptera, Trichoptera and Odonata) for their simplicity since they only require identification with the family.

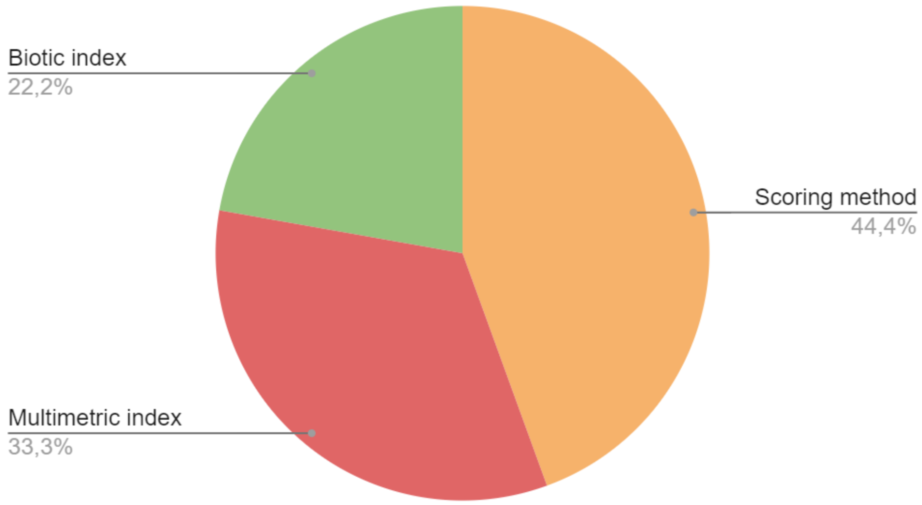

Figure 14: Answers to the question "which existing system would be considered the best bioindicator system for Mexico?

One question concerned the need to combine the bioindicator method with a rapid assessment protocol that takes into account visual information such as habitat quality. All respondents (7 out of 7) answered this question favourably. They were then asked to justify their choice and to specify which parameters they would choose to carry out this protocol. Water quality is a parameter to be assessed for 4 out of 7 people. Some people indicated that this parameter should be evaluated by physical-chemical measurements (2 people), by carrying out analyses of the suspended solids or chlorophyll content, while one person indicated visual evaluation methods (secchi disc or water colour). 1 person does not specify how this parameter should be assessed.

Three out of 7 people choose the quality of the habitat from among the parameters to be assessed. Several people suggest an assessment of the physical quality of the watercourse, such as the dominant vegetation type (1 person) or geomorphology and hydrology (1 person).

Of the 7 respondents, 5 gave their opinion on a preferred taxonomic group for bioindication. The order of diptera, with 26.7%, was the most frequently cited in the responses. In one of the answers, it is specified that only a few families of diptera can be used for bioindication, but they are not specified. Next come, at the same level, odonates, ephemeroptera, trichoptera, plecoptera and hemiptera with 13.3%. We also find beetles in the larval stage, which are mentioned only once (Figure 15). Three families are also cited; the chironomidae, gomphidae and corixidae. One of the respondents did not indicate a preferential taxonomic group but indicated that it should be based on those that are most abundant in Mexico.

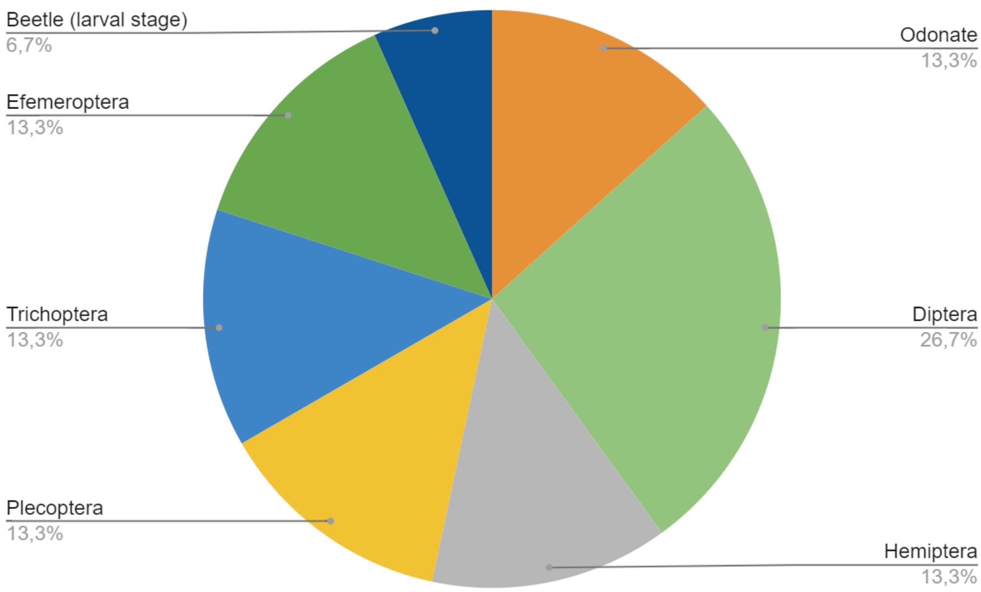

Figure 15: Results obtained for the question concerning preferential taxonomic groups for bioindication

A final question in relation to the type of method to be developed concerned the division of Mexico. Indeed, due to the great heterogeneity of climates and types of regions in Mexico, we wanted to have a professional opinion on the parameters to be chosen for a possible division of Mexico in order to associate a method or variant of method adapted by zone. Even if some parameters are only mentioned once (latitude and longitude, climate, hydrology, geomorphology and habitat type), the explanations provided converge with the main answer; a breakdown by biogeographic zone or ecoregion (36.4%) (Figure 16). In fact, behind all the parameters cited and explanations given by the respondents, the idea of dividing Mexico into zones with similar environmental characteristics stands out. One of the people proposing a division by biogeographical zone specified that it would be important to take into account the diversity of human activities present. The remaining 18.2% of respondents proposed a division by catchment area. One of the arguments put forward for this type of division is the possibility of combining it with the results of physico-chemical analyses from the national monitoring network.

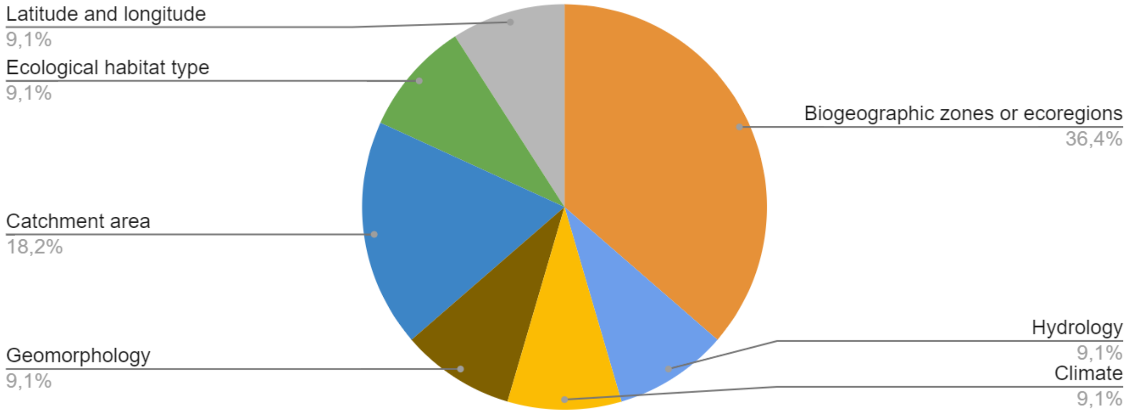

Figure 16: Responses to the question on Mexico's cutting parameters

3.2.2. State of the art on the knowledge of macroinvertebrate ecology

The opinions of the interviewees regarding the development of a specific method for Mexico differed greatly from one person to another. Indeed, 57.1% of the respondents answered "No", i.e. just over half of the people think that it is not necessary to create a specific method for Mexico, while 48.2% answered "Yes", thinking that it is necessary to develop a unique method for Mexico.

As with the previous question, not all respondents have a clear-cut opinion about the potential differences in ecology and reactions to macroinvertebrate pollution. Indeed, 28.6% of them are uncertain and suggest that this similarity may depend on the type of region concerned. However, the answers to the questionnaires tell us that macroinvertebrates sampled in Latin America had similar responses to those sampled in Spain. These macroinvertebrates are: Baetidae, some Plecoptera such as Heptageniidae, Nemouridae or Chloroperlidae and some Trichoptera. On the other hand, 42.9% of those questioned believe that it is not possible to achieve similar pollution tolerances with other European countries or the United States (figure 17).

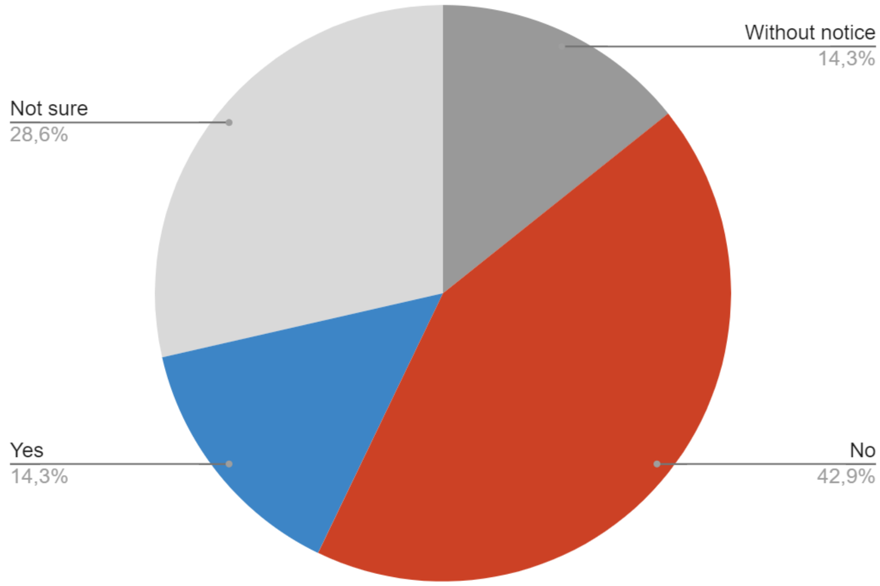

Figure 17: Answers to the question about similarities in pollution sensitivity

Even if the opinion of the respondents differed on the notion of a specific method, they all agreed on the need to adapt the methods developed outside Latin America because they are not intended for tropical areas. Several types of adaptation are suggested;

- taking into account hydrogeomorphological conditions in order to apply a weighting of taxonomic groups according to regions
- calibrate the index according to the basin or system studied
- acquire and use pollution tolerance values adapted to Mexico and its different ecoregions
- increase the number of samples to increase knowledge of macroinvertebrate ecology in the tropics
- testing these methods on tropical systems and calibrating them assess the relevance of the parameters measured
- do not take into account taxonomic groups, but functional groups which, in Mexico, seem more suitable because macroinvertebrates are more sensitive to changes in food resources

It can therefore be seen that the majority of responses converge on the need to develop fundamental research on the ecology of macroinvertebrates in tropical areas in order to adapt bioindication methods to this type of system.

3.2.3. Collaboration with Latin America

Concerning the possibility of creating a method in relation with other Latin American countries in order to develop a unique bioindication method, 71,4% of the respondents think it is possible.

3.3. Proposal for a bioindication method adapted to Mexico and harmonisation of bioindication methods in Latin America

The research carried out and the opinions gathered for this end-of-study project have enabled us to observe that even if bioindication methods are increasingly used in Latin America, they are still very poorly adapted to the multiplicity of biogeographical regions. Moreover, the ecology and the pollution sensitivity of macroinvertebrates are still poorly known.
On the basis of this observation, the aim of this last part is therefore to propose possible solutions in order to develop bioindication in Latin America towards more adapted methods.

3.3.1. The need to develop fundamental research

At present, most of the methods and indices used are based on basic research on macroinvertebrate ecology carried out in Europe or the United States. However, Latin America, belonging to the southern hemisphere, has a much more tropical climate. Thus the majority of the researchers interviewed agree that macroinvertebrates certainly do not have the same ecology and the same pollution sensitivity. It therefore seems necessary to increase studies on the subject in order to know whether the values and indices developed in the countries of the northern hemisphere can serve as a basis for bioindication in Latin America.
However, observations made by Angela Piedad Caro Borrero have led to the conclusion that macroinvertebrates from Latin America and Spain have similar responses.

Another parameter to be taken into account is the multiplicity of climates and ecoregions present within the continent itself. Indeed, we can find arid deserts as well as tropical forests and mountainous regions. It therefore also seems necessary to adapt the indices according to these different regions. Indeed, using the same index would be discriminating for the scores of certain regions in which certain macroinvertebrates are not present due to the nature of the environment and not to the poor quality of the rivers.

In 2008, Abell and his collaborators defined ecoregions corresponding to the earth's freshwater ecosystems based on freshwater fish biological communities, ecological dynamics and environmental conditions. This map is available at www.feow.org. It has been developed with the aim of creating an ecological unit for freshwater ecosystems to assist decision-making in management, planning and conservation (Abell and *al*., 2008), and could therefore serve as a basis for the creation of indices adapted to each ecoregion in Latin America. In contrast to terrestrial or maritime ecoregions, which are largely influenced by climate, physiography and vegetation type, freshwater ecoregions are strongly influenced by the watershed in which they are located. Freshwater invertebrates could not be taken into

account for the delimitation because they can move from one ecoregion to another by land, unlike fish. (Abell and *al*., 2008)

3.3.2. A bioindication common to all Latin America

In view of the previous observation of the need to develop indices adapted to the different types of ecoregions, but aware that each country has very different ecoregions and that it would therefore have to make a considerable effort to produce a method adapted to each of them, the idea would be to involve the countries. Indeed, the different indices to be developed would be distributed among the countries that have a common biogeographical region. Thus the effort to be made for each country would be reduced, but the overall objective would be achieved.
The aim would therefore be to develop a bioindication method, specific to each type of ecoregion but which would be applicable throughout Latin America.

In addition, similar efforts have already been made in the Andes for the development of 4 indices specific not to a country but to a geographical region; the Andean biotic index (ABI) (Ríos-Touma et al, 2014), the Biotic monitoring Patagonian streams (BMPS) (Miserendino and Pizzolon, 1999), the Índice Multimétrico del Estado Ecológico para Ríos Altoandinos (IMEERA) (Villamarín et al., 2013) and the Yungas Biotic Index based on 4 taxa (IBY-4) (Dos Santos et al., 2011).

In Europe such an initiative has already been developed around the AQEM project (Assessment System for the Ecological Quality of Streams and Rivers throughout Europe using Benthic Macroinvertebrates) (AQEM Consortium, 2002). The AQEM project supports the implementation of the EU Water Framework Directive by providing a system for assessing the ecological quality of European rivers with benthic macroinvertebrates. It currently covers 28 river types and enables 8 European countries and their river managers to assess the quality of their rivers. In the same way that we propose to create a method by ecoregion type in Mexico, AQEM has developed a method by river type.

3.3.3. The assessment method choice

As regards the choice of index, the scientific community surveyed does not share a single opinion. Scoring methods, multimetric indices and biotic indices are all cited by 44%, 34% and 22%. Various arguments are put forward for the use of the various methods; some are favoured by their low cost and ease of implementation (scoring method) while others are appreciated because they allow the complexity of natural environments to be taken into account (multimetric index).

In the same way as for the AQEM project (AQEM Consortium, 2002), it is proposed here to develop a multimetric index that allows for the integration of many more factors and thus allows for more in-depth reflection that is not only based on the notions of presence/absence. Indeed, all the scientists questioned agree that parameters such as habitat, physico-chemical and morphological quality and vegetation must be taken into account through a complementary rapid assessment protocol.

Conclusion

The case study on Mexico highlighted the special character of this country, which is considered one of the 18 megadiverse countries in the world, proof of its great biological, climatological and geological wealth (Mittermeier et al., 2008). However, this little-known wealth is also increasingly affected by environmental problems that threaten its biodiversity (Ibáñez, 2019). A growing number of specialised organisations and researchers are looking into this issue, but the knowledge available on freshwater ecosystems and in particular on Mexican macroinvertebrates is still rather weak (Miller et al. 2005). As a result, bioindication using macroinvertebrates is still rarely used in Mexico (Henne, Schneider y Martínez, 2002) as no method has been developed specifically for Mexico to date. However, it should be noted that several methods are being developed, such as the Global Water Watch, based on citizen volunteerism, or the method developed by the Mexican Institute of Water Technologies (IMTA).

In order to help in the development of a method adapted for Mexico and/or more broadly for Latin America, the opinion of 7 specialists was collected in the form of a questionnaire. The analysis of the results showed that certain types of methods seem more appropriate, such as scoring methods or multimetric indices, but that the latter each have their advantages and disadvantages. The first is considered too simple by some researchers to integrate the full complexity of ecosystems and be truly representative of the state of the environment, while the second can be difficult to implement. However, some questions have received fairly unanimous answers, such as the fact that it is essential to adapt the indices according to the specific pollution sensitivity of Mexican macroinvertebrates or those from the same biogeographical region. The interviewees also agreed that the scale of validity of biological indices should be the ecoregion or watershed, but that the scale of a country or continent was not the most appropriate.

We therefore proposed, rather than a method common to all Latin America, a specific method adapted to each ecoregion of this very diverse continent. The implementation of a multimetric index combined with a rapid assessment protocol seems the most appropriate, due to the diversity of its parameters, to be representative of the state of an environment.

Appendix

Appendix 1: List of Latin American aquatic insects and their associated FFGs, based on available information. Source: Ramírez A & PE Gutiérrez-Fonseca (2014). Functional feeding groups of aquatic insect families in Latin America: a critical analysis

Odonata		
Amphipterygidae	Pr	Merritt et al. (2008)
Calopterygidae	Pr	Merritt et al. (2008)
Coenagrionidae	Pr	Merritt et al. (2008)
Dicteriadidae	Pr	Domínguez & Fernández (2009)
Megapodagrionidae	Pr	Merritt et al. (2008)
Lestidae	Pr	Merritt et al. (2008)
Perilestidae	Pr	Merritt et al. (2008)
Polythoridae	Pr	Chará et al. (2012)
Platystictidae	Pr	Merritt et al. (2008)
Protoneuridae	Pr	Merritt et al. (2008)
Pseudostigmatidae	Pr	Merritt et al. (2008)
Synlestidae	Pr	Merritt et al. (2008)
Aeshnidae	Pr	Merritt et al. (2008)
Austropetaliidae	Pr	Domínguez & Fernández (2009)
Cordulegastridae	Pr	Merritt et al. (2008)
Corduliidae	Pr	Merritt et al. (2008)
Gomphidae	Pr	Merritt et al. (2008)
Libellulidae	Pr	Merritt et al. (2008)
Macromiidae	Pr	Merritt et al. (2008)
Neopetaliidae	Pr	Domínguez & Fernández (2009)
Petaluridae	Pr	Domínguez & Fernández (2009)

Order / Family	Functional Feeding Group	Reference
Ephemeroptera		
Ameletopsidae	Pr	Domínguez & Fernández (2009)
Baetidae	Generally CG, *Baetodes* SC	Baptista et al. (2006); Merritt et al. (2008)
Caenidae	CG	Merritt et al. (2008)
Coloburiscidae	Ft	Wisely (1961)
Coryphoridae	Unknown	
Ephemeridae	CG	Merritt et al. (2008)
Ephemerellidae	Generally CG. Some Sc. Few Sh. 1 Pr	Merritt et al. (2008)
Euthyplociidae	CG	Merritt et al. (2008)
Heptageniidae	Generally Sc. Facultative CG	Merritt et al. (2008)
Isonychiidae	Ft, Pr	Merritt et al. (2008)
Leptohyphidae	Generally CG. A few Ft	Merritt et al. (2008)
Leptophlebiidae	Generally CG. Facultative Sc and a few Ft	Baptista et al. (2006); Merritt et al. (2008)
Melanemerellidae	Sh	Molineri & Dominguez (2003)
Nesameletidae	Sc	Hawking et al. (2013)
Oligoneuriidae	Generally Ft	Baptista et al. (2006); Merritt et al. (2008)
Oniscigastridae	CG	Hawking et al. (2013)
Polymitarciidae	CG, Ft	Merritt et al. (2008)
Siphloneuridae	CG	Merritt et al. (2008)

Plecoptera		
Austroperlidae	Sh	Domínguez & Fernández (2009)
Diamphipnoidae	Sc, Sh (*Diamphipnoa* Sc, *Diamphipnopsis* Sh)	Domínguez & Fernández (2009)
Eustheniidae	Pr	Domínguez & Fernández (2009)
Gripopterygidae	Sc, Sh, CG	Domínguez & Fernández (2009)
Notonemouridae	Sc	Domínguez & Fernández (2009)
Perlidae	Pr (early stages Dt)	Merritt et al. (2008)
Hemiptera		
Belostomatidae	Pr	Domínguez & Fernández (2009)
Corixidae	Generally Pc-Hb, some Pr or Sc	Merritt et al. (2008)
Gelastocoridae	Pr	Domínguez & Fernández (2009)
Gerridae	Pr	Domínguez & Fernández (2009)
Hebridae	Pr	Domínguez & Fernández (2009)
Helotrephidae	Pr	Domínguez & Fernández (2009)
Hydrometridae	Pr	Domínguez & Fernández (2009)
Leptopodidae	Pr	Domínguez & Fernández (2009)
Macroveliidae	Pr	Domínguez & Fernández (2009)
Mesoveliidae	Pr	Domínguez & Fernández (2009)
Naucoridae	Pr	Domínguez & Fernández (2009)
Nepidae	Pr	Domínguez & Fernández (2009)
Notonectidae	Pr	Domínguez & Fernández (2009)
Ochteridae	Pr	Domínguez & Fernández (2009)
Pleidae	Pr	Domínguez & Fernández (2009)
Potamocoridae	Pr	Domínguez & Fernández (2009)
Saldidae	Pr	Domínguez & Fernández (2009)
Veliidae	Pr	Domínguez & Fernández (2009)
Trichoptera		
Anomalopsychidae	Sc	Jardim & Nessimian (2011)
Atriplectididae	Pr	Malicky (1997)
Beraeidae	Probably CG	Merritt et al. (2008)
Calamoceratidae	Generally Sh-Dt and Sc	Merritt et al. (2008)
Ecnomidae	Ft?	Merritt et al. (2008)
Glosossomatidae	Generally obligate Sc	Merritt et al. (2008)
Helicopsychidae	Obligate Sc	Merritt et al. (2008)
Helicophidae	CG, Sh	Wiggins (2004)
Hydrobiosidae	Pr	Domínguez & Fernández (2009)
Hydropsychidae	Generally Ft. Some Pr and seasonal Sc	Merritt et al. (2008)
Hydroptilidae	Generally Pc-Hb, Sc, CG	Merritt et al. (2008)
Kokiriidae	Pr	Hawking et al. (2013)
Lepidostomatidae	Obligate Sh-Dt	Merritt et al. (2008)
Leptoceridae	CG and Ft, Sh-Hb, Sc, Pr (*Oecetis* Pr, Facultative Sh-Hb. *Nectopsyche* Sh-Hb, CG)	Merritt et al. (2008)
Limnephilidae	Generally Sh-Dt, Facultative Sh, Facultative CG, some Sh-Hb.	Merritt et al. (2008)
Odontoceridae	Generally Sh	Merritt et al. (2008)
Philopotamidae	Generally obligate Ft	Merritt et al. (2008)
Philorheithridae	Pr	Wiggins (2004)
Polycentropodidae	Generally Ft. Some facultative Pr. *Cernotina* and *Polycentropus* Pr	Merritt et al. (2008)

Xiphocentronidae	CG	Merritt et al. (2008)
Lepidoptera		
Crambidae	Generally Sh-Hb (*Petrophila* Sc, Facultative Sh-Hb, *Neargyractis* Sh-Hb)	Merritt et al. (2008)
Noctuidae	Sh-Hb	Merritt et al. (2008)
Tortricidae	Sh-Hb	Merritt et al. (2008)
Megaloptera		
Corydalidae	Pr	Domínguez & Fernández (2009)
Sialidae	Pr	Domínguez & Fernández (2009)
Neuroptera		
Osmylidae	Pr	Domínguez & Fernández (2009)
Sisyridae	Pr	Domínguez & Fernández (2009)
Mecoptera		
Nannochoristidae	Pr	Domínguez & Fernández (2009)
Sericostomatidae	Generally Sh	Merritt et al. (2008)
Stenopsychidae	Unknown	
Tasimiidae	Sc	Wiggins (2004)
Coleoptera		
Chrysomelidae	Sh-Hb (L and A)	Merritt et al. (2008)
Curculionidae	Sh-Hb (L and A)	Merritt et al. (2008)
Gyrinidae	Generally Pr (L and A)	Merritt et al. (2008)
Noteridae	Pr, CG (L). Pr (A)	Merritt et al. (2008)
Amphizoidae	Pr (L and A)	Merritt et al. (2008)
Dytiscidae	Generally Pr (L and A)	Merritt et al. (2008)
Dryopidae	Generally Sh-Hb (L). Generally Sc, Sh-Hb (A)	Merritt et al. (2008)
Elmidae	Generally CG, Sc, Sh-Hb (L and A)	Merritt et al. (2008)
Haliplidae	Generally Sh-Hb, Pc-Hb, some Pr (L and A)	Merritt et al. (2008)
Hydroscaphidae	Sc (L and A)	Merritt et al. (2008)
Hydrophilidae	Generally Pr (L). Generally CG (A)	Merritt et al. (2008)
Hydraenidae	Pr (L). Sc, CG (A)	Merritt et al. (2008)
Lampyridae	Pr	Domínguez & Fernández (2009)
Lepiceridae	Unknown	
Limnichidae	Generally CG? (L and A)	Merritt et al. (2008)
Lutrochidae	Sh-Dt, Hb (L and A)	Merritt et al. (2008)
Meruidae	Unknown	
Ptilodactylidae	Generally Sh-Dt, Hb (L)	Merritt et al. (2008)
Psephenidae	Sc (L) (Adult NonFeeding)	Merritt et al. (2008)
Ptilidae	Sc (A)	Merritt et al. (2008)
Scirtidae	Generally Sc, CG, Sh-Hb, Pc-Hb (L)	Merritt et al. (2008)
Staphylinidae	Pr, CG, Sh-Hb (A)	Merritt et al. (2008)
Blephariceridae	Generally Sc	Merritt et al. (2008)
Ceratopogonidae	Generally Pr, some facultative CG and Sc	Merritt et al. (2008)
Ceratopogoninae	Generally Pr, a few CG	Merritt et al. (2008)
Forcipomyiinae	CG, Sc?	Merritt et al. (2008)
Corethrellidae	Pr	Merritt et al. (2008)
Culicidae	Generally Ft and CG	Merritt et al. (2008)
Chironomidae	CG and Ft, Pr	Merritt et al. (2008)
Chironominae	Generally CG, Ft	Merritt et al. (2008)
Diamesinae	Generally CG, Sc	Merritt et al. (2008)

Orthocladiinae	Generally CG, Sc	Merritt et al. (2008)
Podonominae	CG, Sc	Merritt et al. (2008)
Tanypodinae	Pr	Merritt et al. (2008)
Chaoboridae	Pr	Merritt et al. (2008)
Deuterophlebiidae	Obligate Sc	Merritt et al. (2008)
Dixidae	CG	Merritt et al. (2008)
Dolichopodidae	Generally Pr	Merritt et al. (2008)
Empididae	Generally Pr	Merritt et al. (2008)
Ephydridae	Generally CG, Sh-Hb, Sc, Pr	Merritt et al. (2008)
Muscidae	Generally Pr	Merritt et al. (2008)
Pelecorhynchidae	Pr, Sh-Hb?	Merritt et al. (2008)
Psychodidae	Generally CG (*Maruina* Sc, CG)	Merritt et al. (2008)
Ptychopteridae	Generally Obligate CG	Merritt et al. (2008)
Sarcophagidae	CG	Merritt et al. (2008)
Simuliidae	Generally Obligate Ft, some Sc, Pr and facultative CG	Merritt et al. (2008)
Sciomyzidae	Generally Pr	Merritt et al (2008)
Stratiomyidae	Generally CG	Merritt et al. (2008)
Syrphidae	CG	Merritt et al. (2008)
Tabanidae	Generally Pr	Merritt et al. (2008)
Thaumaleidae	Sc	Merritt et al. (2008)
Tipulidae	Generally Sh-Dt, CG (*Hexatoma* Pr, *Limonia* Sh-Hb, *Tipula* Obligate Sh-Dt, Facultative Sh-Hb and CG)	Merritt et al. (2008)

FFG classification must be made at the genus or species level and this list is a preliminary guide for those interested in working on the topic. The assignment of more than one FFG per family is the reflection of the diversity within a family. When most groups within a family belong to a few FFG, it is stated as "generally" or "some". A few families that completely lack information are listed as "unknown." Question marks (?) denote when the assignment is questionable. Updates to this list will be posted online (http://www.ramirezlab.net/research/ffg/).

A=Adult, L=Larvae, CG=Collectors-Gatherers, Ft= Filters, Pr=Predators, Pc=Piercers, Sh=Shredders, Sc=Scrapers. For some cases, trophic guild information is provided to clarify their functional role: Dt=Detritivores; Hb=Herbivores. Thus, a Sh-Dt is a shredder on plant detritus, not of live tissue; while a Sh-Hb is a shredder on live plant tissue.

Appendix 2 : IMTA field sheets

Logo IMTA	**INSTITUTO MEXICANO DE TECNOLOGIA DEL AGUA** **LABORATORIO DE CALIDAD DEL AGUA** **FICHA DE CAMPO DE MACROINVERTEBRADOS BENTICOS**

NOMBRE DEL RÍO:		LOCALIDAD
ESTACIÓN #______		CLASE DE RÍO
LAT______________ LONG______________		CUENCA
INVESTIGADORES		REGIONAL
LLENADO POR:	DÍA:______________ HORA______________ AM PM	PROYECTO:

NO. DE CONTROL: ____________________

CONDICIONES CLIMÁTICAS	☐ Tormenta ☐ Lluvia ☐ Lluvia intermitente ☐ % Cobertura Nubes_____ ☐ Claro / Soleado Lluvias en los 7 días pasados ☐ Sí ☐ No Temperatura ambiente__________ºC Otros______________________
LOCALIZACIÓN DEL SITIO / MAPA	Dibuje un mapa del sitio e indique las áreas del muestreo o agregue una fotografía.
	Subsistema del Rio ☐ Perenne ☐ Intermitente ☐ Estacional **Origen del Rio** ☐ Poza ☐ Mixto ☐ Arroyo ☐ Otro__________ **Tipo de Rio** ☐ Agua Fría ☐ Agua Tibia **Área de la cuenca**_______Km²

FIRMA DE ANALISTA: NOMBRE:					FIRMA DEL RESPONSABLE: NOMBRE:				
Edición:	D	M	A	Sustituye a:	D	M	A	Revisión:	Hoja 1 de 2

FCAHB-32A

Logo IMTA	*INSTITUTO MEXICANO DE TECNOLOGIA DEL AGUA* *LABORATORIO DE CALIDAD DEL AGUA* *FICHA DE CAMPO DE MACROINVERTEBRADOS BENTICOS*

CARACTERÍSTICAS DE LOS APORTES AL AGUA	**Uso predominante de suelo** ☐ Bosque ☐ Comercial ☐ Pastizal ☐ Industrial ☐ Agricultura ☐ Otros______ ☐ Residencial **Evidencia de contaminación** ☐ Ninguna ☐ Alguna fuente potencial ☐ Fuente obvia **Erosión local** ☐ Ninguna ☐ Moderada ☐ severa
VEGETACIÓN RIPARIA	**Indique la dominancia del tipo de especies de vegetación presentes** ☐ Árboles ☐ Arbustos ☐ Pastos ☐ Herbáceas **Presencia de especies dominantes**____________________
CARACTERÍSTICAS DEL RIO	**Estimación de la longitud**________m **Estimación del ancho**________m **Alcance del área de la muestra**______m **Área en Km² (m²x1000)**___Km² **Estimación de la profundidad promedio**______m **Velocidad superficial máxima**____m/sec **Cobertura de dosel** ☐ Parcialmente abierta ☐Parcialmente sombreada ☐ Sombreada **Marca de altura máxima del nivel del agua**_______m **Tipo de morfología** ☐ Rápidos_____% ☐ Pozos____% ☐ Corriente____% **Canalizado** ☐ Sí ☐ No **Presencia de presa** ☐ Sí ☐ No
VEGETACIÓN ACUÁTICA	**Indique el tipo de dominancia** ☐ Enraizadas emergentes ☐ Enraizadas sumergidas ☐ Enraizadas sumergidas ☐ Libre flotadoras ☐ Algas flotantes ☐ Algas adheridas **Presencia de especies dominantes**____________________ **Porcentaje de cobertura de la vegetación acuática**__________%
CARACTERÍSTICAS DEL AGUA	Temperatura____________°C Conductividad____________ Oxígeno disuelto__________ pH_________ Salinidad ____________ Solidos disueltos totales ______ **Olores en el agua** ☐ Normal / Ninguno ☐ Pescado ☐ Químicos ☐ Petróleo ☐ Drenaje ☐ Otros____________ **Presencia de aceites** ☐ Sí ☐ No **Transparencia** _____ Equipo usado ______________
TIPO DE HABITAT	**Indique el porcentaje de cada tipo de hábitat presente** ☐Trocos sumergidos______% ☐ Canto rodado_____% ☐ Bancos de vegetación_____% ☐ Arena______% ☐ Macrophytas sumergidas______% ☐ Otros( )_____%
FORMA DE COLECTA	Tipo de red ☐ D-frame ☐ Pateo ☐ Otra________
COMENTARIOS GENERALES	

COMPONENTES INORGÁNICOS DEL SUSTRATO

Tipo de sustrato	Diámetro	% Presente en la muestra
Placa de piedra		
Roca	>256mm (10")	
Canto rodado	64-256mm (2.5"-10)	
Grava	2-64mm(0.1"-2.5")	
Arena	0.06-2mm	
Arena fina	0.004-0.06mm	
Arcilla	< 0.004mm	

COMPONENTES ORGÁNICOS DEL SUSTRATO

Tipo de sustrato	Características	% Presente en la muestra
Detritus	Materia Orgánica partículas grandes	
Lodos	Materia orgánica partículas finas	
Otros	Fragmentos de conchas	

Profundidad: __________ Velocidad: ___________

Edición:	D	M	A	Sustituye a:	D	M	A	Revisión:	Hoja 2 de 2

FCAHB-33B

Appendix 3 : Questionnaire sent in Latin America

Cuestionario sobre bioindicación en México y América Latina para profesionales

Directores del proyecto: Karl M. Wantzen (Cátedra UNESCO Cultura Fluvial – River Culture), Melanie Kolb (professora en geografia, UNAM)

Estudiantes: Roxane Bigot - Stana Savattier

Por favor, devuelva el cuestionario rellenado a:

roxane.bigot@etu.univ-tours.fr o stana.savattier@etu.univ-tours.fr

Presentación: Muchos países utilizan métodos muy diferentes para evaluar la calidad del agua mediante especies indicadoras (principalmente invertebrados bentónicos). En América Latina, algunos países han modificado el BMWP, otros usan los índices sapróbicos o los índices multimétricos (a partir de métodos americanos o europeos) o han desarrollado sus propios métodos de bioindicación.

El proyecto en el cual se ubican el proyecto de las estudiantes, se desarrolla bajo los auspicios de la Cátedra UNESCO de Cultura Fluvial – River Culture y el instituto de geografia de la UAM, y tiene por objetivo revisar el uso actual de los sistemas de bioindicación en Latino América, así como investigar oportunidades de desarrollar nuevos sistemas de bioindicación en México. El objetivo de este estudio es recoger datos y la opinión personal de los actores principales con interés en los bioindicadores acuáticos para elaborar una propuesta de bioindicación de macroinvertebrados en México. Roga-se de cumplimentar el formulario presente en bajo.

Nombre : **Apellido :**

Empresa/Organismo :

Función/Puesto :

Correo electrónico :

1. ¿Tiene experiencia personal de trabajo con sistemas bioindicadores de la calidad del agua utilizando invertebrados bentónicos o ha estudiado sistemas potenciales en teoría ?
   Sí / No

2. ¿Tiene experiencia con uno o más sistemas bioindicadores diferentes?
   Sí / No
   Si es así, ¿cuáles?
   Respuesta corta

3. En relación con su experiencia sobre la aplicación de los métodos de bioindicación que utilizan macroinvertebrados bentónicos específicos de México, ¿podría proporcionarnos información en el siguiente cuadro?

Nombre del sistema	Dónde/cuándo se aplicó	Publicación de los resultados (citación/URL/DOI)	Persona de contacto (nombre/correo electrónico)	Evaluación (éxito o fracaso)

4. Como resultado de sus experiencias, ¿qué sistema existente consideraría el mejor sistema bioindicador para México? (Puntuación, índices bióticos, BMWP, índices multimétricos, otros, que ?)
   Respuesta corta

En caso afirmativo, ¿puede describir las ventajas de este sistema sobre otros sistemas? (por ejemplo, ¿hay razones prácticas, como el tiempo de manipulación de las muestras, la simplicidad de la identificación, etc.)
Respuesta exhaustiva

¿Cree que este método puede aplicarse tal como está, o cree que los métodos requieren más mejoras? ¿Qué tipo de mejora?
Respuesta exhaustiva

5. O, alternativamente, ¿considera necesario desarrollar un sistema específico para México? Sí / No

En caso afirmativo, ¿qué calidad(es) indicadora(s) de organismos utilizaría como base para el sistema?
Respuesta exhaustiva

6. ¿Cree que sería útil que un sistema bioindicador se combinara con un protocolo de evaluación rápida, que combine información visual sobre la calidad del hábitat?
   Sí / No

   En caso negativo, ¿por qué? :

En caso afirmativo, ¿cuáles? :

7. ¿Cree que los macroinvertebrados de una determinada familia o género podrían tener el mismo comportamiento y la misma sensibilidad o tolerancia a la contaminación en Europa, Estados Unidos y México?
   Respuesta corta

8. ¿Qué grupos taxonómicos de macroinvertebrados consideraría de mayor importancia para una bioindicación en México?
   Respuesta corta

9. ¿Existe ya un inventario de la calidad de los ríos y taxones presentes. En caso afirmativo, ¿podría proporcionarnos información en el siguiente cuadro?

Nombre del río	Dónde/cuándo se aplicó	Publicación de los resultados (citación/URL/DOI)	Persona de contacto (nombre/correo electrónico)	Evaluación (éxito o fracaso)

10. Si dividiera México en zonas en las que se utilizaran diferentes métodos de bioindicación (o subconjuntos de especies para un solo método), ¿qué sistema de zonificación elegiría? (en lo que respecta a las zonas biogeográficas, la altitud, el clima, la hidrología, etc.)
    Respuesta exhaustiva

11. ¿Cree usted que sería posible colaborar con otros países de América Latina para desarrollar un método armonizado para toda América Latina?
    Respuesta corta

12. ¿Ya colaboran con países de América Latina? En caso afirmativo, ¿podría proporcionarnos información en el siguiente cuadro?

Países	Método	Citación/URL/DOI/attach the method descritpion	¿Cómo fueron sus experiencias?

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Water quality assessment of rivers using macroinvertebrates in Latin America : Progress report and focus on Mexico

Summary :

Latin America is currently facing real challenges concerning the management of its rivers and the quality of its water. In spite of a later awareness compared to developing countries, almost all countries use bioindication by macroinvertebrates. About 32% of them directly apply the methods developed by the countries of the northern hemisphere, while 73% adapt these methods or develop others, so that they correspond better to the macroinvertebrate fauna of Latin America. In fact, it has not been proven that macroinvertebrates from both hemispheres have the same pollution sensitivity and ecology.

It therefore seems necessary to develop methods that are more specific to tropical areas and based on fundamental research into the pollution sensitivity of macroinvertebrates living there. However, the sub-continent has a multiplicity of ecoregions (arid deserts, tropical forests, mountains, etc.). In order to be able to produce indices adapted to each type of ecoregion and to reduce the effort required for each country, it is proposed that countries with common ecoregions collaborate. In this way, there would be an index adapted to each type of ecoregion, but it would be applicable throughout Latin America.

Key words : Latin America, bioindication, macroinvertebrates, pollution sensitivity, ecoregions, harmonisation.