THE LIMNIC FOOTPRINT INDEX

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ABSTRACT. - The Limnic Footprint Index. Inspired by the ecological footprint, a limnic footprint index is created by the authors of this article to quantify the weight of all water bodies (lakes, ponds, pools, swamps, marshes ...), irrespective of their size and origin (natural or artificial), on a territory. This limnic footprint takes into account both the global problem of the role of water bodies in the climate machine and in all the biogeochemical cycles, but also local questions about the linkages with ecosystems and sociosystems. To do this according a geosystemic limnological geography approach, two spatial criteria that are the extended limnic ratio and the density of water bodies will be considered at an equal level, without preconceived dominance of one of the parameters on the other. Conceived as a tool for representation and comparison, the limnic footprint index is scalable in the sense that it adapts to the overall scope studied. Applied at the European Union level, this index modifies fundamentally the spatial representation induced by the only scientific consideration currently taken of large-scale water bodies and especially of natural origin. In fact, the sensitive issue of water bodies is primarily the sign of a large northwest quarter of Europe.

Keywords: Index, Limnic Footprint, Water bodies, Limnology, Management.

1. INTRODUCTION

An indicator is a qualitative or quantitative variable allowing a simplified assessment of an abstract phenomenon: it participates in an evaluation process that statistically reflects a reality for the understanding of a fact by a society. Since water is one of the major global issues of the twenty-first century, sciences studying this element must have multiple indicators to regulate its uses and characterize the territories where people live. Creation of spatial indicators by hydrological sciences may assist political management of water and produce a tool of representation and comparison.

In Limnology, the spatialized approach to the multitude of water bodies is limited to a single indicator, namely "limnic ratio" (Penck, 1894), which characterizes only the water surface areas of the great natural lakes. In fact, diversity of scientific approaches which take into account the plurality of types of water bodies is not quantified by one or more indicators.

In terms of management, based on the case of the European Union where the administrative structuring of water is driven by multiple directives such as

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WFD-2000 (Water Framework Directive), the aim is to achieve "good ecological status", taking into account theoretically the societies living in the territory to be managed and their socio-economic-environmental expectations. Civil society would like to think from a systemic and spatial point of view, but it adopts in fact a rigid framework, both scientific and cartographic, which is found in exclusively naturalistic indicators and does not lead to a consideration of diversity.

In a limnological geography approach (Touchart et al., 2014) that puts the water body and the diversity of approaches into the focus of interactions between society and environment on various spatial and temporal scales, we propose to produce a spatial indicator capable of making it join the scientific approaches of the limnology and their integration in a concrete way by society in a given territory.

Through the creation of a Limnic Footprint Index (LFI) applied to the territories, partly inspired by the conceptual model of ecological footprint, we will try to answer this lack of common goals between "sciences" and "political management" in producing new statistical data that we will map on the European Union level and which we will discuss.

2. HOW TO RECONCILE SCIENCES AND SOCIETAL MANAGEMENT WITH A TERRITORIAL STATISTICAL APPROACH TO WATER BODIES?

2.1. Limnic ratio was until now the only scientific spatial approach focused on water bodies

Since the prevalent topic was physiogeographical, great lakes were enhanced: the number of water bodies did not matter, the surface area was the only criterion. In this sense Penck (1894) coined in German the neologism “share of water at the surface area”, later renamed limnic ratio in English, suggesting that the interface hydrosphere / atmosphere was more important than the relations between the hydrosphere and the lithosphere and even between the hydrological spheres. These pioneering works were continued and led to establish a database grouping the great (i.e. more than 500 km²) lakes of the world. The prevalence of limnic ratio over other possible indicators (such as mean relative depth of water bodies in a territory or density of water bodies) has ever since been confirmed by the authors claiming a spatial approach in limnology.

2.2. A lack of a limnocentric approach to societal management.

The regulatory translation on water bodies at European level has necessarily been inspired by scientific knowledge, but since the subject matter is water in all its forms and not only water bodies the territorial approach to water is profoundly different. The indicators set up differ according to the category of "water masse" to which the water body to be managed (WFD-2000) is attached.

Thus, the regulatory territory may correspond to two types: either the sovereign state or the river basin managed by a water agency. In both cases, the limnic entry is neglected since the first management perimeter is of a politico-administrative nature while the latter is fluviocentric.

In fact, the spatial indicator of "good ecological status" of the water masses concerns, for surface waters, the principle of the section of watercourses. The sections are cut out according to the hydro-ecoregions (Wasson et al., 2004) conceptually based on running waters and exclusively on physical parameters. In fact, only a few lakes larger than 50 ha are actually considered as "water bodies" but they are isolates within this set built by hydraulic engineers.

This apprehension of waters has provoked numerous controversies likes the question of territorialisation built by a "biocentric" or "ecocentric" management without the incorporation of sociosystem, necessary approach to governance using time scale (Germaine and Barraud, 2013).

Thus, while limnology favors a territorial approach based on the only limnic ratio indicator, regulatory governance ignores most water bodies and does not put in place an indicator to facilitate its management models. However, many scientific upheavals have been lately observed, and neither limnology nor governance, have yet learned from these developments. These are three mutations that all refer to limnological geography even if they do not only come from geographers: interest in artificial and not only natural water bodies, inventory of smaller bodies of water such as ponds or swamps and indeed, since these "new" limnic objects are very related to the anthroposystem, study of spatial and temporal variations both cartographic and systemic. The origin of this global approach is found in the attempt to integrate water bodies into the climate machine.

2.3. Quantification of the role of water bodies in the climate machine: the need to improve territorial limnic indicators for societal use.

This evolution is rooted in the work of Wetzel (1990) on the possibility of a major role of water bodies and especially the smallest of them on the global climate. To validate this hypothesis, many researchers have worked to better quantify and map these, but at very variable scales. Some of them have compiled existing local databases on a global scale (Meybeck, 1995), while other researchers have tested new methods to this inventory. This is the case primarily of the mathematical extrapolation (log-log plot) as for the researches of Hakanson and Peters (1995) at the scale of Sweden or those of Downing and Duarte (2009) on a global scale, generating figures without maps, and the remote sensing through programs such as GLWD (Lehner and Döll, 2004) and GLOWABO (Verpoorter et al., 2014) where, on the contrary, each encrypted data is accompanied by a more or less precise cartography.

It is worth noting a generalized race towards the distinction of small bodies of water, both in detection and in the conceptualization of mathematical models (Downing and Duarte, 2009), but on the other hand, this approach is very poorly accompanied by a clear distinction between natural and artificial creations. But after all, from a limnological geography perspective and not from ecology, is it really fundamental? Relative temporality teaches us that natural lakes can be of extremely recent creation without generating ecosystemic particularities, while centuries-old ponds (Bartout, 2015) can generate remarkable biodiversity.

On the other hand, the use made of these global inventories by trying to apply them locally meets the misunderstanding of both natural and anthropogenic characteristics of the territory on which they are installed (Bartout et al., 2015). In this sense, local inventories based partly on field expertise for exhaustiveness have the merit of existing generally up to a low limit of 0.01 ha which is "*the size threshold approved by researchers working on global counts*" (Rjanžin, 2005).

Gradually, the total number of identified or supposed water bodies will inflate (up to 117 million for Verpoorter et al. in 2014) while the limnic ratio shows practically no increase. The primacy of limnic ratio on the density of water bodies then becomes more questionable as a reference spatial indicator. Bartout (2012) goes so far as to criticize the very adequacy of the term limnic ratio since it characterizes in essence territories filled with natural lakes. However, this new limnic ratio reflects the presence of lakes, ponds and swamps, whether of natural or artificial origin. In fact, the more globalizing term "extended limnic ratio" was preferred.

The multiplicity of spatial approaches in limnology thus complicates today the identification of an indicator synthesizing all of them without giving more importance to one of them than to another. To translate this complexity into the multiple regulatory challenges that prioritize this or that parameter, we have therefore decided to create a new indicator that we have taken the approach to ecology because the Limnic Footprint of a territory may be regarded as the Ecological Footprint of a place.

3. THE LIMNIC FOOTPRINT INDEX, CALIBRATOR OF LIMNIC TERRITORIES AT DIFFERENT SCALES.

3.1. How to calculate a Limnic Footprint Index?

In order to escape from the only framework of the limnic ratio traditionally used in limnology for naturalistic purposes, we have added to it the multiplicity of lentic objects for its developmental purposes. In fact, taking into account these two equal criteria does not determine a priori any domination of the natural part on the anthropogenic part, of the evaporating surface on the system of drainage of the water or even of the singular limnosystem on the plural limnosystem.

The LFI therefore responds to a systemic logic in geography where the different components are at the same level without the domination of one on the other(s). To achieve this, we have to satisfy several stages:

- An inventory as exhaustive as possible with the same methodologies / objectives and the same surface limits (low as high);

- Calculate the extended limnic ratio for each identified territory; Calculate the average of the limnic ratio for all selected territories; Create an index of the limnic ratio for each of the territories, the average being 1: the higher the number, the greater the spatial footprint of the bodies of water and vice versa;

- Calculate the density per km² of the bodies of water of the selected territories; Calculate the average density for all selected territories; Create a density index for each of the territories, the average being 1: the higher the number, the greater the hydrosystemic footprint of the water bodies and vice versa;

- Create the LFI by adding the index of limnic ratio to the density index, then divide by two: the more the number obtained will be close to 1, the more the Limnic Footprint of the territory concerned will be close to the average of the global territory; The higher this number, the more this index will highlight a need for limnic management to be taken into account by the actors; The lower the number, the less limnic management will cover the importance of the general understanding and balance of the natural and landscape structures of the territory.

This indicator is therefore intended, with a view to management, to highlight the footprint of the bodies of water by comparing several territories between them and thus define the one where the limnic theme is the most pregnant. The LFI can only be meaningful from the moment when at least two separate territories, irrespective of their area, are compared.

3.2. Application to the European Union territory.

To symbolize the great natural lakes, we used the WISE Large Lakes base of the EEA, which officially includes 221 lakes for 52,249 km². To portray the bodies of water officially recognized as such by the European leaders, we used the Lakid_O field of the Ecr_15 base developed by the EEA where 85,172 water bodies for 74,389 km² are figured. Finally, to represent the diversity of European water bodies, we relied on the new crossing of the Ecr_15 base previously quoted with the *OpenStreetMap* base (OSM) freely supplemented by European citizens (or not), i.e. 1,259,288 water bodies for 126,591 km².

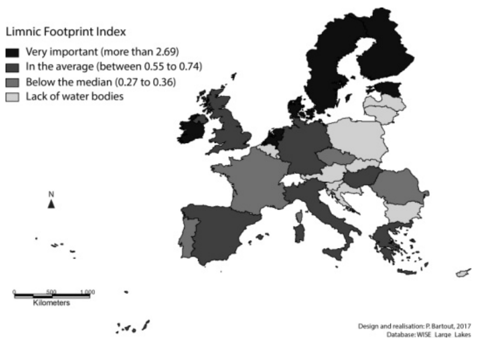

Fig. 1. ***The Limnic Footprint Index in European Union according to a classical limnological approach***

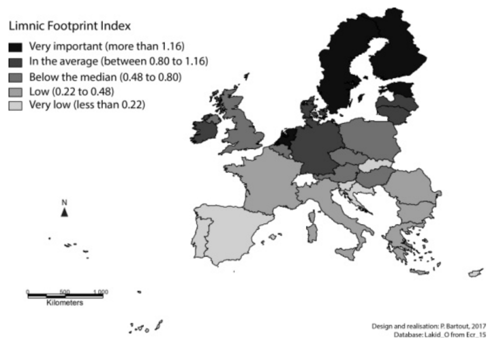

Fig. 2. ***The Limnic Footprint Index in European Union according to a regulatory approach with prescribed data***

Figure 1 representing the LFI according to the classical approach of limnology from the only great natural lakes demonstrates an overwhelming domination of northern Europe (Sweden, Finland, Estonia, Denmark, the Netherlands and Republic of Ireland) with respect to the rest of the Union. These six states all possess at least more than two and a half times the average LFI, while none of the other states reaches three-quarters of the average LFI.

Figure 2 representing the LFI according to a regulatory approach produces a very different cartography, both in its values and in its geography. Indeed, the extreme values disappear and there is a form of cartographic progressiveness separating the north and south of Europe according to a line from the Benelux and going to Hungary. A closer look shows a secondary fracture line at the scale of these two subsets, the eastern part appearing more limnic than the western part.

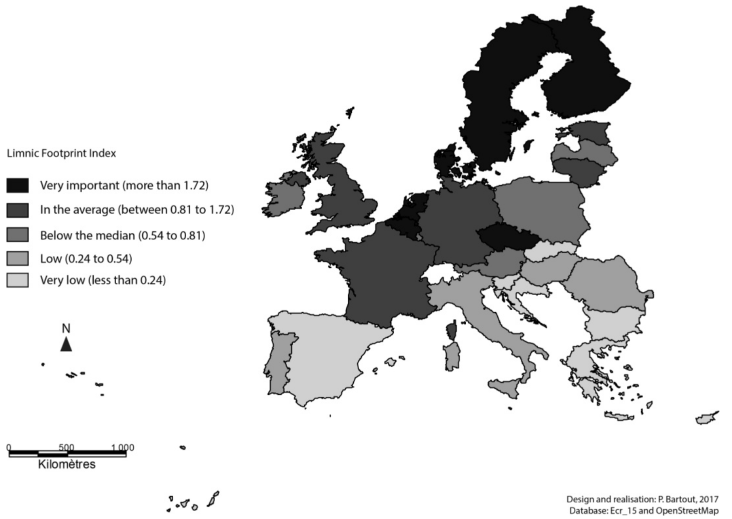

Fig. 3. ***The Limnic Footprint Index in European Union according to a limnogeographical approach (all sizes and all types of water bodies)***

However, this geographical peculiarity is no longer evident when we look at the map representing a more complete inventory of limnic diversity, both in size and origin (figure 3). This map is very different from the previous two. Admittedly, the north of Europe (Sweden, Finland) still has a very important LFI, but the northeast does not concentrate the highest LFI. The northern central part shows high index, or even more largely the north-north-west including France. The European gradient is then more in a north-west/southeast logic where the lowest values of the LFI are located in the Balkan Peninsula and in Spain.

This figure 3 deeply changes the spatial perception which was until now too centered on natural lakes and suffered from chronic underestimation of small artificial water bodies. Rather, it highlights the diversity of water bodies, what implies other systemic links.

3.3. Discussions

Two sources of the LFI need to be discussed, i.e. the used database and the geographical coverage.

The authors of this paper favored an inventory methodology that is similar from one country to another, in order not to distort the comparison. Nevertheless, the new database resulting from the cross-referencing between Ecr_15 and OSM, although it greatly improves all the existing databases of water bodies on the European scale, is not exhaustive. Indeed, several references (*in* Bartout, 2015) mention larger water areas (Germany, Austria, Hungary, Latvia, Poland) or more numerous water bodies (Denmark, Sweden), or both (Estonia, France, Finland, Romania, Slovenia), calling into question the calculation of the indicator. We checked this difference for two countries which we directly (France) or indirectly (Estonia) supervised methodology, data processing and mapping. Discrepancy between figures is important for the calculation of the third LFI, especially for density. Our new inventory allows mapping 103,456 water bodies in Estonia and 655,893 in France, whereas the previous one respectively mapped 8,141 and 240,533 of them.

In that respect, the use of our new, more accurate, data raises the Index of Estonia from 1.2161 to 3.0682 (2^{nd} state of the EU after Denmark) and that of France from 0.9619 to 1.3156 (5^{th} place).

The LFI may be adapted according to each geographical coverage. Thus, data can be discussed on a smaller cartographic scale (for instance the European continent or even the world) to show the overrepresentation or under-representation of a country. On a larger cartographic scale, the subdivision of a country may show its homogeneity or on the contrary its limnic heterogeneity.

4. CONCLUSION

The LFI is a significant step forward in integrating spatial limnology and societal needs, since it improves first and foremost the consideration of water bodies' variety. Until now, this diversity was not enough emphasized by limnic ratio (and even extended limnic ratio), because of the overwhelming area of great lakes. In the same way, the only spatial criterion of density did not into account sociosystem and geographic identity of a limnic territory (Bartout and Touchart, under press) because it was not able to separate a country with numerous small natural lakes and another with artificial water bodies. By associating at the same level the two spatial criteria, the LFI allows to produce new maps of limnic territories. On the scale of European Union, the usual oversized focus on Northern countries (especially Sweden and Finland) is called into question. Indeed, limnic peculiarities of other regions such as north-western Europe are worthy of consideration. This would make it possible to give a better idea of their genesis and thus to improve their management by making more compatible scientific aims of "good ecological status" and legitimate expectations of the people.

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