Method for the rapid assessment and potential mitigation of the environmental effects of development actions in riparian zone

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Highlights

- An indicator-based approach is proposed to assess the effects of management actions
- The assessment of the effects are performed at very short, short and medium terms
- Improvement actions are proposed to attenuate the impacts
- The method was designed to be simple, flexible and fast to implement
- The method was applied to a French site

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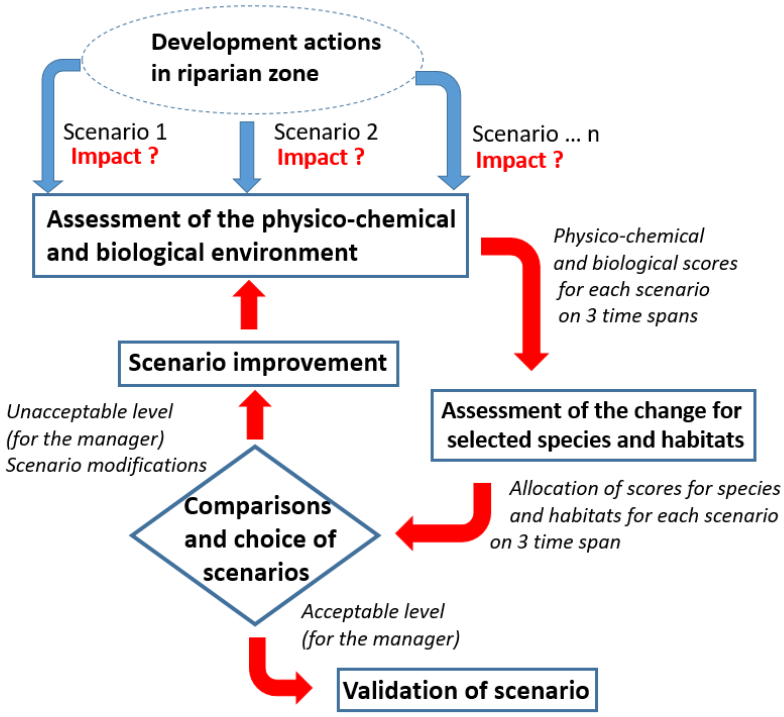
Abstract

Watershed and river managers often face difficult choices between safety issues related to floods and degraded hydraulic structures, requiring urgent works and involving environmental stakes such as biodiversity, landscapes and rare species. These choices require taking precise ecological data and existing knowledge into account. Unfortunately, such databases and pre-existing knowledge are rarely available or they are only fragmentary and exist at the local scale for parts of areas classified as protected, or they are limited to a few species. Obtaining these data is time and money consuming and requires significant means, which is incompatible with the need to take urgent decisions. The aim of our work was to develop a flexible, easy to use and rapid method that does not wholly rely on accurate and comprehensive datasets and knowledge. It was designed to meet the need for fast assessment with limited means, which is a frequent case, particularly when urgent decisions are required or when the human and environmental stakes are circumscribable. The method uses an indicator-based approach to assess the effects of various management scenarios on the systems. Actions leading to the potential mitigation of these effects can be proposed. The method was implemented on the Grand Buech river in La Faurie (French Alps) where works were required to improve the safety of dikes. The impact of three management scenarios was assessed on 8 species and habitats. The results showed that, in the medium term, two scenarios may improve the current situation while the last one could worsen it. The method could be adapted to most watersheds and impact assessment in other environments.



Graphical abstract

keywords

Watershed management,decision-making tool, riparian zone assessment, fluvial and riparian ecosystem, indicator.

1.Introduction

The riparian zone along rivers is a specific biome composed of three main compartments: watercourse, terrestrial environments and riparian vegetation. It plays an important ecological role in ecosystem balance and its functions depends on many interacting factors (Barbier et al., 2009; Forio et al., 2017).

These zones fulfil different fundamental ecological functions (Gundersen et al., 2010) and produce ecosystem services. In particular, they offer specific natural habitats with unique ecological communities (Stella et al., 2013) and distinctive species (Santos, 2010). They also form biological corridors, increasing ecological connectivity, and therefore play a major role in biodiversity maintenance (particularly for forests and watercourses). The riparian zone protects water quality and the wetland parts of the catchment against pollution (Pinay et al., 2001; Dosskey et al., 2010). It also protects banks and soils from erosion, and plays a key role in buffering water temperature (Groom et al., 2011). Finally, according to (Naiman *et al.*, 1993; Naiman and Decamps, 1997), riparian zones have exceptionally diverse arrays of species and habitats.

However, rivers have been exploited and managed by humans for a long time. Major developments involving civil engineering, including dikes and dams, have been generalized to prevent floods, develop land for agriculture, create waterways, etc. Obviously these numerous works have effects on the physico-chemical characteristics (water levels, velocities, etc.) and the biological characteristics (longitudinal and local connections, dendrological integrity, etc.) of the riparian zone and consequently on animal and plant species and habitats. These issues have been considered from a political viewpoint (Vigier et al., 2019): Europe has issued directive on water quality (Water Framework Directive (European-Commission, 2000)). These European texts have been transposed into French law at the national level, then at the river basin, district and local levels. The French government has also considered the issue of biodiversity recovery. Moreover, the aim of the MAPTAM Act(JORF, 2014) was to clarify and reinforce various decentralized competences. Among them, a new responsability called GEMAPI ("Joined Management of the Aquatic Environment and Flood Prevention") was assigned to municipalities and public inter-municipality cooperation establishments on 1 January, 2018. It is composed of four paragraphs of the Environmental Code (JORF, 2019):

(1°) development of a watershed or a fraction of a watershed;

(2°) maintaining and developing a watercourse, canal, lake or water body, including access to them;

(5°) preventing river and sea floods;

(8°) protecting and restoring sites, aquatic ecosystems and wetlands as well as riparian woodlands.

In this context the public actors in charge of GEMAPI must manage the riparian zone, considering both flood control and ecosystem preservation. They need relevant information on the environmental effects of management and heavy maintenance actions to choose among various management scenarios, and define corrective actions to mitigate these effects. In this article we present a method to predict over the very short to medium terms and then monitor the effects of management actions on a riparian zone. Like many other approaches already proposed in the litterature, this method relies on indicators. Many of them deal with a diagnostic task.

Cai and Zhang (2018) emphazised the use of multi-scale ecological indicators in recent works and then categorized them into four groups: (i) mechanism investigation and analysis; (ii) watershed assessment and evaluation; (iii) watershed management modeling; (iv) water- and eco-system analyses. Other researchers have proposed an indicator-based framework integrating aquatic and terrestrial ecosystems to diagnose and evaluate ecosystem health (Wu et al., 2015) .

The major environmental variables used to predict ecological water quality, assessed through several water quality characteristics, have been determined (Forio et al. 2017). A conceptual framework relying on the development and integration of a set of hydrological and biologic indicators has been proposed (He et al., 2000). It shows the modified spatial and temporal distributions of hydrological and biological conditions which result from land use/cover changes across the watershed studied (de Zwart et al., 2009). Some authors have considered the sensitivity of structural and functional indicators related to the type and resolution of anthropogenic activities to select the most relevant indicators during a diagnosis (Yates et al., 2014). In a recent study, important insights into the hydrological effects of river restoration were obtained but the author did not address the impacts on the ecosystem (Clilverd et al., 2016). Another common approach deals with ecosystem services or functions (Meyer, 1997; Nakamura et al., 2006; Brauman et al., 2007; Vidal-Abarca et al., 2016; Martin et al., 2018), i.e. the social benefits of ecosystems, in terms of who benefits and by how much, to facilitate comparing multiple courses of action. They mainly considered an anthropocentric viewpoint and societal requirements (Meyer, 1997; Brauman et al., 2007). Finally, research has been conducted on the determination of impacts of various types on animal and plant species: for instance, the impact of climate change on Australian seabirds and pinnipeds (Wilcox et al., 2018); the impact of tourism on stream fish (Bessa et al., 2017); the impacts of infrastructure on bird electrocution (Pérez-García et al., 2016) and the impacts of climate change and land-use scenarios on Margaritifera margaritifera (Santos et al., 2015).

Most existing studies and those cited above are based on accurate contemporary or historical sources, photographs and topographic surveys, or in situ measurements and monitoring (Bertoldi et al., 2009). Unfortunately, such data and preexisting monitoring are rarely available for most rivers, or they are only fragmentary and concern local scales in areas classified as protected, or rare species. Obtaining these data is time-consuming and may require many years and significant resources.

Our work is aimed at developing a flexible, easy to use method that does not fully rely on accurate and comprehensive datasets or validated local knowledge. It is designed to meet the needs of performing fast assessments with limited means, which is the most frequent case, particularly when urgent decisions are required due to safety problems, when the problems to be solved are limited to the local scale or when there are no major stakes.

The goal is to help forecasting the impacts of management actions on a set of biotic and abiotic indicators, including aquatic and terrestrial species living in the impacted zone, and designing mitigation actions considering very-short to medium terms. This method can be used to compare scenarios of watercourse developments within the GEMAPI framework in France, and in similar contexts elsewhere.

2 Methods and case study

2.1 Method

2.1.1 Identification and formalization of indicators to assess the changes induded by the management actions on the physical and biological environment

The first step consists in the development of an approach for the assessment of the changes induced by the management actions on the physical and biological environment. More precisely, we developed an indicator-based approach. In order to make them robust, these indicators were formalized as grids following the principle described in Curt *et al.* (2010). The indicators were formalized using expert knowledge and document analysis. In particular, we used the results of different research works (Haury *et al.*, 2006; Carnino, 2010; Bensettiti *et al.*, 2012; Viry, 2013; Gayet *et al.*, 2016) to identify the effects of development plans on the aquatic environment and the forest environment associated with a riparian zone. These project effects were split into two types: physico-chemical and biological (vegetation structure, invasive alien species, etc.). A first list of indicator stemming from this literature had been proposed to four senior experts from INRAE (French National Institute for Agriculture, Food, and Environment) participated in the choice and design of the method: their expertise covered aquatic ecology, terrestrial ecology, hydraulics works and decision support. There was an overlap of competencies in the group of experts, concerning hydraulic works and decision-support. Expert knowledge is commonly used as a surrogate of empirical data in many fields of ecological research (Drescher et al., 2013). Knowledge formalisation and the development of the method was managed by a mediator who coached the elicitation sessions. The experts defined the indicators from their knowledge. Grids were composed with a definition and a rating scale with anchorage points.

2.1.2 Identification of species and definition of the effects on the biotic indicators

The second step aims at developing an approach to assess the effects of the physico-chemical and biological changes on the biotic indicators. First, a selection of species and habitats must be performed, faced with the very large number of species referenced in aquatic and forest environments. The selection method should focus either on the species most sensitive to the impact of the project, or on "remarkable" or "specific" ones populating the area affected by the works. This choice must represent several "still alive" species in the aquatic and terrestrial natural environments. They are classified into categories such as fishes, crustaceans, insects, mammals, plants species, etc. The selection process can also highlight species or habitats with anthropic issues (social, economic, recreational or agricultural activities, etc.).

Once the species and habitats are identified, the impacts of each scenario on each of them must be evaluated. To this aim, we used the results of different researchers (Devillers *et al.*, 1991; Ormerod *et al.*, 1993; Bryce *et al.*, 2002; Brin *et al.*, 2009). The assessment is completed by consensus after discussion with field managers specialized in hydraulic works, hydrology, and the ecology of aquatic or terrestrial environments. This assessment is carried out for indicators whose value estimated during phase 1 is different from zero. An indicator equal to zero means that the scenario has no effect on the environment.

2.1.3 Definition of the final decision

The aim of the last phase is to reach the final decision for the development works. The preferred scenario is that which has the most positive (or at least less negative) impact on selected species and habitats in the medium term. This scenario can also be improved following the recommendations of the experts.

2.2 Case study

The method was applied to a torrential river in the municipality of La Faurie, in the Buëch watershed in the French Alps. This zone belongs to two classified areas: a ZNIEFF (French Natural Zone of Ecological, Faunistic and Floristic Interest, number. 930020125, (https://inpn.mnhn.fr/, and EU NATURA-2000 site No. FR 9301519 (defined by European Directives92/43/EECand 79/409 / EEC
(https://ec.europa.eu/environment/nature/natura2000/faq_en.htm).
This river and its watershed are managed by the SMIGIBA, which is a local, public institution in charge of managing the Buëch River and its tributaries. It gathers all the municipalities of the Buëch Valley. Its administrative and technical staff have skills in ecology, geomorphology and hydraulics.

After the last major rain episode from (22 to 25 November 2016), the freshet incised the foot of the dike at La Faurie by regressive erosion, amplifying the risk of overflow on the RD 28 road and in the village.

The municipality wished to carry out reinforcement works on the damaged dike. The SMIGIBA and a design office identified three scenarios

- The scenario 1 proposed to renovate identically the dike (but vegetated only by grasses);

- The scenario 2 suggested the partial levelling of the dike and the implementation of a non-jointed stone wall on the lower 2/3 of the dike along with shrubs planted in the interstices on the lower slope, the upper third being vegetated with shrubs or grasses;

- The scenario 3 solution consisted in bed widening with the installation of a bench terrace 50 m from the bed.

Constraints are both the reduction of the vulnerability of La Faurie village and the preservation and even improvement of the territory’s natural environment for "green tourism" and biodiversity. Consequently, a method to analyse the impact of such scenarios on the ecosystem was developed. We considered the study site as a single physico-chemical system (water level, speed, etc.) and a single biological system (longitudinal and local biological connections, etc.). Remote effects from upstream or downstream were not considered.

3. Results: assessment of the effect of scenarios on the ecotone and application to a case study

As shown in Figure 1, the assessment of the effect of scenarios on the ecotone has four main phases.

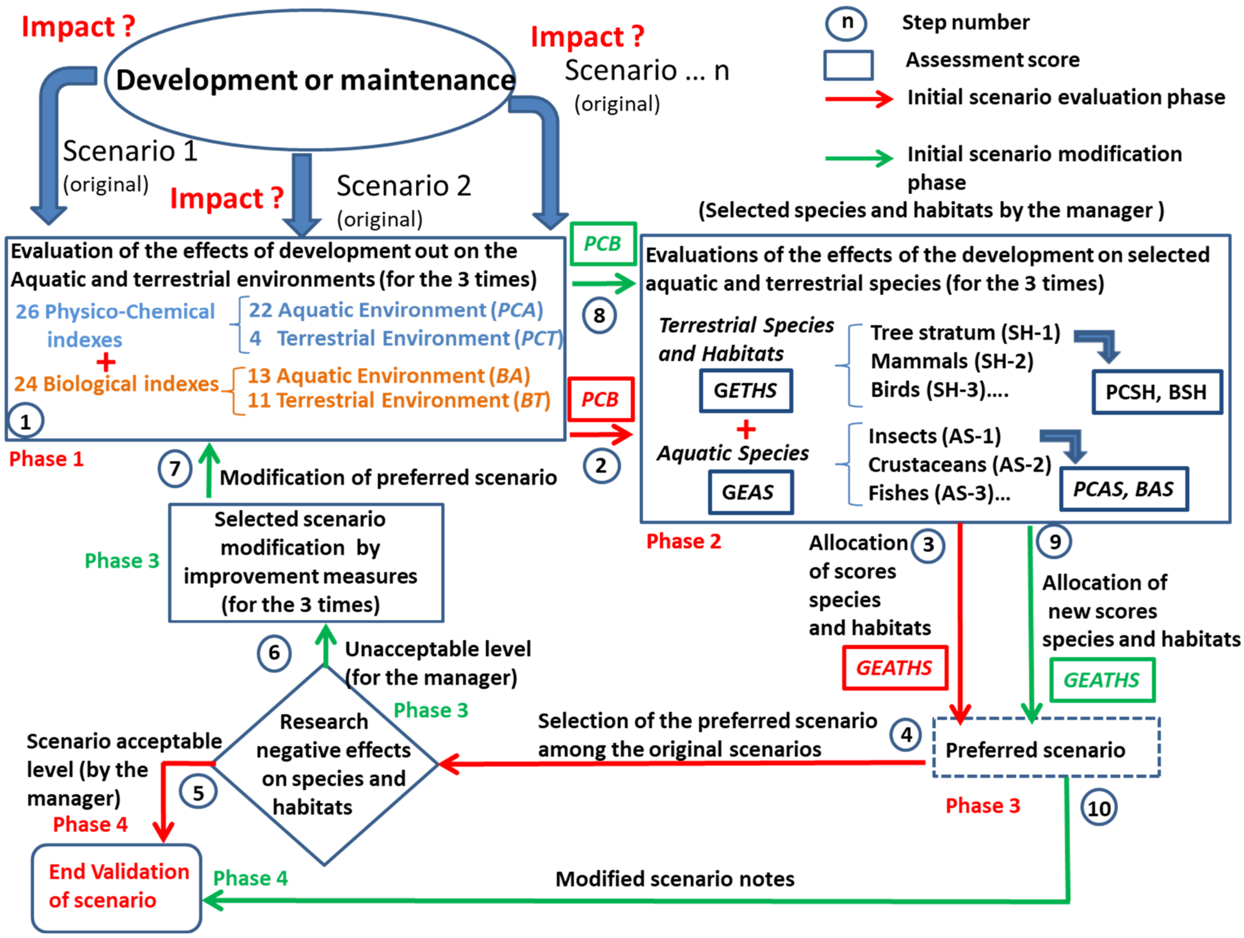


Fig. 1: Illustration of the phases proposed for the rapid assessment and potential mitigation of the environmental effects of development actions in riparian zone.

3.1 Assessment of the physico-chemical and biological environment

During this phase (Phase 1 on Figure 1), we sought to evaluate elements of the riparian ecosystem characterized by biological and ecological processes.

3.1.1 Identification of indicators

Fifty indicators were produced (tables 1 and 2): 35 concerning the Aquatic Environment (22 Physico-chemical Indicators coded PCA and 13 Biological Indicators coded BA) and 15 concerning the Terrestrial Environment (4 Physico-chemical Indicators coded PCT and 11 Biological Indicators coded BT).

Physico-chemical Indicator for Impacted Aquatic Environment (PCA_n – n is the indicator number given in brackets)	**Indicator definition**

Spatio-temporal dynamics (1)	Evolution of the spatio-temporal dynamics, of the "fluvial style" or the general shape of the riverbed (number of channels…).
Riverbed width (2)	Evolution of the average width of the river bed (active strip) over the section studied
Average water depth (3)	Evolution of the average water level over a year
Minimum water depth (4)	Evolution of the lowest water level over a year
Average water velocity (5)	Evolution of the average water speed over a year
Maximum water velocity (6)	Evolution of the highest water speed over a year
Morphometric discontinuities (7)	Evolution of natural discontinuities (appearance/disappearance of water holes, small rapids, etc.)
Hydraulic margins (8)	Evolution of hydraulic annexes (small permanent or temporary tributaries, wetlands, ponds, flood plains, etc.)
Brightness (9)	Evolution of the average brightness in the river It determines the presence or absence of certain species by its daily or seasonal variations
Water temperature (10)	Evolution of water temperature
Oxygen balance sheet (11)	Evolution of the average annual value of the dissolved oxygen concentration
Salinity level (12)	Evolution of the salt content in the watercourse
Acidification level (13)	pH evolution in the watercourse
Nutrient concentration (14)	Appearance/Disappearance of nitrophyte macrophytes
Flood morphometric action (15)	Alluvial surface evolution
Hydrology in flood phase (16)	Evolution of the overflowing flood regime
Hydrology during the low water phase (17)	Evolution of flow assessed when the level of the watercourse is at its lowest point
Water table depth (18)	Evolution of the depth between the soil surface (bottom of the riverbed) and the water table
Bed load (rolling or bouncing along the bottom) (19)	Evolution of the bottom load of (rather coarse) sediments in the riverbed which are entrained by the waters during important hydrological phenomena (flood, barrage flush ...)
Suspended load fractions (20)	Evolution of sediments of small size in the flow mass
Aquatic environment use (21)	Evolution of human attendance, development of recreational activities (canoeing, fishing, etc.)
Degradation of water intake (22)	Evolution of flow (irrigation, a sewage treatment plant, a factory ...)
Physico-Chemicals Indicator for Impacted Terrestrial Environment (PCT_n – n is the indicator number given in brackets)	**Indicator definition**

Thermal regulation, brightness and wind-break (23)	Evolution of thermal regulation, brightness and wind-break
Soil and cover (24)	Evolution of soil erosion and runoff
Hydrological and morphological (25)	Evolution of the environment (channelization, artificialization of banks, exploitation, drainage of lands and wetlands)
Evolution of use related to riverbank and forest environments (26)	Changes in the allocation of riverbanks and forest environments (landscape quality), development of recreational activities (hunting, mountain biking, fishing, horse riding, etc.)

Table 1: List of "Physico-chemical" Indicators for Impacted Aquatic Environments (PCA) and Impacted Terrestrial Environments (PCT).

Biological Indicator for Impacted Aquatic Environment (BA_n – n is the indicator number given in brackets)	**Indicator definition**
Mini fauna (other than fish) (27)	Evolution of number specimen of benthic macro-invertebrate.
Longitudinal local biological connections (28)	Evolution of exchanges between upstream and downstream parts, as well as between the river and its tributaries
Lateral local biological connections (29)	Evolution of riverbank layouts making the moving or exchange of species more difficult
Vertical local biological connections (30)	Evolution of exchanges between the river and groundwater interface area (hyporheic zone)
Ecological state of aquatic flora (31)	Evolution of the ecological state of the aquatic flora (aquatic plants visible to the naked eye)
Substrate composition (32)	Evolution of the thickness and composition of the substrate (materials, particle size, etc.) constituting the bed of the watercourse and serving as a support for living organisms
Deadwood (on the ground or not) (33)	Evolution of the number of dead wood (habitat/refuge for wildlife)
Agricultural runoff (34)	Evolution of the runoff stemming from the agricultural area (pollution by nitrates...) impacting the biotope mainly due to treatment of crops with fertilizers, manure discharges and herd excrement
Urban Runoff (35)	Evolution of the runoff stemming from the urban area impacting the biotope mainly due to hydrocarbons, so-called heavy metals (mercury, lead, zinc).
Maintenance of the aquatic environment and aquatic vegetation (36)	Evolution of the number or intensity of intervention on aquatic environment.

Water level variations (37)	Evolution of the number or intensity of barrage flush amplitude (passage very fast from high to low phase of river or vice versa)
Riverbed dredging (38)	The evolution of "the cleaning" of the river bed (development a deficit in materials, more stresses on the banks and a tendency to "meander" causing an erosion which destabilizes the bank, leading to serious consequences for the biotope of the ecosystem)
Invasive alien species (Fauna and Flora) (39)	Frequency of observation of invasive alien species
Biological Indicator Terrestrial for Impacted Environment (BT_n – n is the indicator number given in brackets)	**Indicator definition**
Habitat surface (40)	Evolution of the area covered by vegetation
Site fragmentation (caused by infrastructures, housing, etc.) (41)	Evolution of the number of infrastructure (road, houses, fields, etc.) in and around the impacted environment
Dendrological integrity (42)	Evolution of the surface or number of taxa of indigenous trees
Invasive alien species (43)	Frequency of observation of invasive alien species
Composition of herbaceous layer and moss (44)	Evolution of the stratum (floristic composition and ages)
Composition of shrub layer (45)	Evolution of the stratum (floristic composition and ages)
Composition of tree layer (46)	Evolution of the stratum (floristic composition and ages)
Dead wood (47)	Evolution of the dead volume to total volume ratio
Riparian forest and forest environment maintenance (48)	Evolution of the number or intensity of intervention on Riparian forest and forest environment.
Purifying functions concerning runoff stemming from agricultural areas (49)	Evolution of the runoff stemming from the agricultural area (pollution by nitrates...) impacting the biotope mainly due to treatment of crops with fertilizers, manure discharges and herd excrement
Purifying functions concerning water runoff stemming from urban areas (50)	Evolution of the runoff stemming from the urban area impacting the biotope mainly due to hydrocarbons, so-called heavy metals (mercury , lead, zinc)

Table 2: List of "Biological" Indicators for Impacted Aquatic Environments (BA) and for Impacted Terrestrial Environments (BT).

3.1.2 Indicator formalization

All the indicators were assessed on the same scale with two sets of references : quantitative (-10, -5, 0 , +5, +10) and qualitative (High Decrease; Low Decrease; No Change; Low Increase; High Increase). If the impact was unknown, then the score assigned was equal to -10.

For example, the indicator "Substrate composition (32)" was designed to control the evolution of the thickness and composition of the substrate (materials, particle size, etc.) constituting the bed of the watercourse and serving as a support for living organisms. If during the work an excavator must enters the river bed, then it is very likely that the composition of the substrate is clearly impacted and its quality is degraded in the very short term. Thus the note falls to -10 in this case. However, in time, the substrate quality progressively recovers and value shifts - to -5 and 0 in the short and the medium term respectively.

Although the method can be used and its results interpreted without the need for a specialist or expert in each field, it is preferable that the ratings are formulated by consensus during collective sessions involving a group of experts with complementary and overlapping skills.

3.1.3 Assessment periods

The notion of resistance, recovery and resilience has become a key concept in ecosystem management. This triple concept generally refers to the ability of an ecosystem to overcome natural upheavals during a hazard and to rebuild afterwards. Ecosystems have always undergone natural disturbances such as severe floods in rivers and forest fires that can renew the ecosystem by clearing dead vegetation and releasing seeds for regeneration. The problem arises when the disturbances result from human activity (development works). Human-caused disturbances to the environment often result in harm that goes beyond what the ecosystem can sustain in a "natural" way and challenge its ability to resist and recover in human-life time. This is why we evaluated impacts according to three timespans:

- The "very-short" term (vst), approximately two years (post-works period), can be related to the resistance concept. During this first phase, the natural environment should start winning back. The assessment will be used in particular to highlight the immediate effects (negative, neutral or positive) that a development scenario may have on the environment and to consider, if necessary, improvement measures (introduction of fascines, implementation of a fish pass, etc.) to modify the scenario planned and reduce its impact on the "environment".

- The "short" term (st), approximately 8-10 years, corresponds to the period when "the natural environment" may rapidly regain ground. We link this state to the recovery concept.

- The "medium" term (15-20 years) (mt) corresponds to the period when the riparian biotope may recover most of its balance and interaction richness, even if still not identical to the original state. This can be related to the resilience concept.

We have deliberately not considered the "long term" which may be much longer for wooded riparian environments (Newaz *et al.*, 2019): up to more than 60 years for forested banks (Hupp, 1992), because tree size and stand structure matter for wooded environments and we

do not have clear future perspectives. French riparian zones are very often anthropized, so it is very difficult to predict human impact on this type of area beyond 20 years, especially in an evolving context within global changes.
Finally, 150 indicators (50 indicators for 3 different times) had to be assessed for each development scenario. For example, if it is planned to cut down woody vegetation (trees and shrubs) that has grown on a levee, then these works will result in a significantly increased exposure to light and temperature of previously shaded areas. Therefore, aquatic environment indicators “temperature” (PCA_9_vst) and “light” (PCA_10_vst), should be assessed as +10 (High Increase) in the short term. This score will be kept for st and mt, because this action must be repeated frequently to prevent trees settling on the levees.

3.1.4 Information necessary for the assessment

To evaluate the effects of a development on the environment (species and habitats), it is essential to sufficiently characterize and understand the impacted territory. The set of data necessary varies depending on the environments and constraints concerned. For our case study of a river and riparian vegetation, compulsory information included:

- the geology of the concerned section (to assess land erosion, the suspended load fractions indicator, and substrate composition);

- the typology of "Climate" including the number of freeze-thaw days to assess the hydraulic regime (in low-flow and flood phases);

- "flood hazard" with the referencing of floods and overflows (taking past events into account);

- natural disaster,

- risks of technological origin;

- networks: water, electricity, city gas, pipeline, internet, etc.;

- road transport, railway (pollution runoff, salt, pollution following accidents, etc.);

- factories, institutions (with stock) and Seveso sites (high or low threshold), livestock farming, silo, pressing, etc.

3.1.5 Global assessment of the effects on the environment (PCB)

In order to globally evaluate the physico-chemical and biological effects of a development on the environment (PCB), the mean of the scores of all the indicators is computed for each term (vst, st, mt). PCB_mt is presented below as an example:

$$\boldsymbol{PCB\_mt} = \frac{\sum_{n=1}^{Nb_{PCA}} \boldsymbol{PCA\_n\_mt} + \sum_{n=1}^{Nb_{PCT}} \boldsymbol{PCT\_n\_mt} + \sum_{n=1}^{1Nb_{BA}} \boldsymbol{BA\_n\_mt} + \sum_{n=1}^{Nb_{BT}} \boldsymbol{BT\_n\_mt}}{(\boldsymbol{Nb_{PCA}} + \boldsymbol{Nb_{PCT}} + \boldsymbol{Nb_{BA}} + \boldsymbol{Nb_{BT}})} \tag{1}$$

With:
- n: indicator number;
- mt: medium term (15-20 years);
- Nb_PCA: number of Physico-chemical indicators for the Aquatic environment;
- Nb_PCT: number of Physico-chemical indicators for Terrestrial environment;
- Nb_BA: number of Biological indicators for the Aquatic environment;
- Nb_BT: number of Biological indicators for the Terrestrial environment.

The same calculation is performed for very short (PCB_vst) and short (PCB_st) terms.

3.1.5 Application to La Faurie case study

Differences between scenarios were tested with a pairwise comparison. Scenarios did not differ significantly on the very short term (Table 3 and 4, $P > 0.05$). These scores reflected the inevitable immediate negative environmental impacts generated by works. The sensitivity of our tool takes on its full meaning for this case study in the short term. Indeed, differences between scores became significant ($p < 0.0001$): scenario 3 shifted to a positive score while both other scenarios remain negative despite an improvement showing that, for scenarios 1 and 2, the ecosystem recovers slower. In the medium term, all scores increased compared to the short term, with scenarios 1 and 2 getting close to 0, the differences remaining significant with scenario 3 ($p<0.0001$). This suggests an improvement of the ecosystem in scenario 3 while both other scenarios lead to a simple resilience to pre-existing level. Again, the tool shows a good sensitivity discriminating between the three scenarios.

PCB	**2 years**	**8-10 years**	**15-20 years**
Scenario 1	-2.9	-0.2	0
Scenario 2	-3.4	-1.1	0.1
Scenario 3	-1.6	2.3	4.1

Table 3: assessment of the development scenarios of La Faurie dike (mean values).

Table 4 shows the comparison for the 3 scenarios and the 3 terms

Timespan	Ratio F	Probability
Very Short Term	1.78	P = 0.178
Short Term	11.86	P <0.0001
Medium Term	17.05	P <0.0001

Table 4: pairwise comparison (Statgraphics v18x64) results for the 3 scenarios and the 3 terms

3.2 Assessment of the selected species and habitats

3.2.1 Selection of species and habitats

The aim of this phase (Phase 2 on Figure 1) is to define the effects of a given scenario on selected species and habitats. The selection of species and habitats led the expert panel to retain 8 species faced to 1017 in our case study of La Faurie sector: Fishes (*Telestes souffia*), Crustaceans (*Austropotamobius pallipes*), Mammals (beaver: *Castor fiber*), Aquatic Insects (*Coenagrion caerulescens*), Chiropterans (bat: *Rhinolophus hipposideros*), Birds (*Charadrius* *dubius*), Insects (*Rosalia alpina*), Plants species / habitats (Alpine rivers and their ligneous vegetation with willow: *Salix elaeagnos*).

3.2.2 Assessment of scenario impacts on each selected species and habitat (SH)

As the effects of the development scenario can be different over time, certain species or habitats can be impacted, for instance, within a very short term but not within the short or medium terms.

The evaluation is carried out using the double scale described over (qualitative or quantitative): the impacts of scenarios on the "biotic" environment are graded with a scale ranging from -10 to +10 (-10 / High negative impact or unknown impact; -5 / Low negative impact; 0 / No change; +5 / Low positive impact; +10 / High positive impact). Four types of variable are assessed during phase 2: Effect of Physico-chemical indicators on Aquatic Species (PCAS_m_t_i), Effects of Biological indicator on Aquatic Species (BAS_m_t_i), Effects of Physico-chemical indicator on Terrestrial Species and Habitats (PCSH_m_t_i) and Effects of Biological indicator on Terrestrial Species and Habitats (BSH_m_t_i). m indicates the number of indicators assessed as different from 0 during phase 1; t the period of assessment (t = vst, st, mt); i the considered species or habitat.

To be objective, the assessment of constraints, requirements, potential threats and management proposals, etc. for each species, should be derived from existing studies and management recommendations from classified or protected areas, when they exist.

For example, one of the recommendations in the EU Natura 2000 sheet (1087) for the insect "*Rosalia alpina*" is to preserve dead trees in riparian corridors because its larvae live in dead wood. In our method, the presence of dead wood is related to the biological indicator "dead wood volume / total volume ratio ". Thus, if this indicator is scored -10 (strong decrease of dead wood), the impact on “*Rosalia alpina*” will be very harmful and assessed as -10 (PCSH_47_mt_Rosalia = -10). Conversely, if dead wood is left in place (dead wood volume / total Indicator ratio = +10), then the effect on *Rosalia* is assessed as +10 (PCSH_47_mt_Rosalia = +10). Conversely, there is no impact of the presence of dead wood on the birds selected, for instance (PCSH_47_mt_ *Charadrius dubius* = 0).

If several species belonging to the same category such as "birds" are evaluated and their score is not identical, the least favourable score is kept for the effect calculation.

Also, for this phase the effects are evaluated over the three-time scales: very short (2 years), short (8-10 years) and medium (15-20 years). The evaluation in time and according to each scenario of all selected species and their habitat, highlights the most accurate and integrated knowledge of their specificities.

Equation 2 (Terrestrial species or Habitat) and Equation 3 (Aquatic and semi-aquatic Species) are given as examples for an assessment in the medium term.

$$SH\_i\_mt = \frac{\sum_{1}^{Nb\_PCSH} PCSH\_m\_mt\_i + \sum_{1}^{Nb\_BSH} BSH\_m\_mt\_i}{(Nb_{PCSH} + Nb_{BSH})}$$
(2)

With:
- m: indicator number;
- i: terrestrial species or habitat index
- mt: medium term (15-20 years);
- Nb_PCSH: number of Physico-chemical indicators considered for the selected Terrestrial Species or Habitat impacted;
- Nb_BSH: number of Biological indicators considered for the selected Terrestrial Species or Habitat impacted.

$$AS\_i\_mt = \frac{\sum_{1}^{Nb\_PCAS} PCAS\_m\_mt\_i + \sum_{1}^{Nb\_BAS} BAS\_m\_mt\_i}{(Nb_{PCAS} + Nb_{BAS})}$$
(3)

With:
- m: indicator number;
- i: aquatic or semi-aquatic species index
- mt: medium time (15-20 years);
- Nb_PCAS: number of Physico-chemical indicators considered for the selected Aquatic or semi-aquatic Species impacted;
- Nb_BAS: number of Biological indicators considered for the selected Aquatic or semi-aquatic Species impacted.

The same computation is carried out for the very short (vst), and short (st) terms.

3.2.3 Global assessment of scenario impacts

The global assessment allows monitoring the impacts of each scenario according to environment types (aquatic or terrestrial). In addition, these global indicators are calculated on the basis of the assessments performed for the different species and habitats selected. The same weight is given to all environment types.

Equation 4 illustrates the Global Effect on the selected Terrestrial selected Species and Habitats in the medium term:

$$GETSH\_mt = \frac{\sum_{1}^{Nb\_TSH} SH\_i\_mt}{Nb\_TSH}$$
(4)

$$GEAS\_mt = \frac{\sum_{1}^{Nb\_AS} AS\_i\_mt}{Nb\_AS}$$
(5)

With:

i: terrestrial species or habitat index
mt: medium term (15-20 years)
Nb_TSH: number of terrestrial species or habitats considered in the study
Nb-AS: number of Aquatic and semi-aquatic Species considered in the study

The same computation is carried out for the very short (vst), and short (st) terms: for Terrestrial Species and Habitats (GETSH_vst, GETSH_st) and for Aquatic and semi-aquatic Species (GEAS_vst and GEAS_st).

Finally, the Global Effects of the development on Aquatic, Terrestrial, Habitats Species (GEATHS) is calculated as:

$$\boldsymbol{GEATHS\_mt} = \frac{\boldsymbol{GEAS\_mt + GETHS\_mt}}{\boldsymbol{2}} \tag{6}$$

The same computation is carried out for the very short (GEATHS_st) and short (GEATHS_st) terms.

The GEATHS scores are first used to compare the global effects of the different scenarios and, secondly, to select the "preferred" scenario.

3.2.4 Application to La Faurie case study

In this part, we assessed the impacts on the individual species and habitats selected by managers for the three temporalities and according to the proposed dike development scenarios.

There were few discrepancies between the three scenarios (Figure 2 and table 5) when considering the global effects on all the species and habitats (GEATHS) at very short time. The mean scores were similar around - 4 to -5, which corresponds to a low negative impact. However, the impact was higher for Terrestrial Species and Habitats (GETHS) than for Aquatic species (GEAS). Moreover, the impacts were highly variable within species in a given habitat and between habitats depending on the scenarios. For example, for the beaver, the impacts of some scenarios were quite low because this species only pass briefly in transit in this area (Figure 2). On the contrary, especially for scenario 2 *Austropotamobius pallipes* and *Telestes souffia* suffered from the physical alteration of the banks, entailing in particular a change in the thermal and light balances, as well as changes in lateral connections. Moreover, they were affected by the displacement of riprap and the passage of construction machinery in the riverbed, leading to the disappearance of morphological discontinuities, and the modification of the lateral and vertical connections and of the substrate condition.
These potential impacts will require special attention and "continuous control" of the riparian ecotone beyond 2 years.

	Scenario 1			Scenario 2			Scenario 3		
Time / Results	**2 years**	**8-10 years**	**15-20 years**	**2 years**	**8-10 years**	**15-20 years**	**2 years**	**8-10 years**	**15-20 years**
Selected species and habitats									
Global Effects on Aquatic Species (GEAS)	-1.8	1.5	2.7	-4.4	-1.1	2.1	-2.5	2.2	4.5
Global Effects on Terrestrial Species and Habitats (GETHS)	-6.4	-5.2	-5	-5.3	-4.6	0.5	-6.5	-2	3.1
Global Effects on Aquatic, Terrestrial, Habitats , Species (GEATHS)	-4.1	-1.9	-1.2	-4.9	-2.9	**1.3**	-4.5	**0.1**	**3.8**

Table 5: Results of the development evaluation scenarios of La Faurie dike.

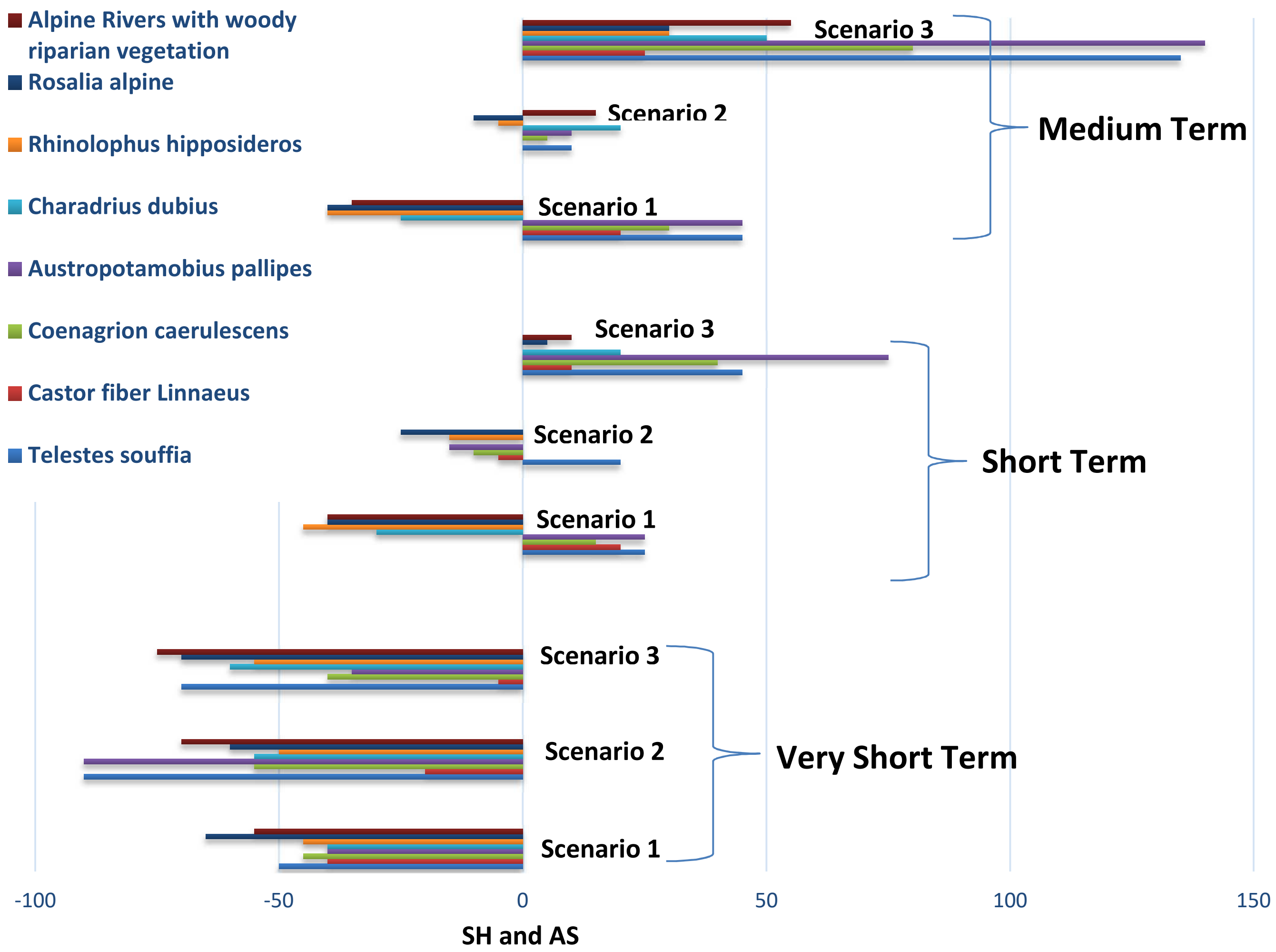


Fig. 2: Representation of consensual ratings of effects to evaluate the scenarios for the 3 terms for selected Species and Habitats.

In the short term, the scores of the scenarios for the Aquatic species, were improved for the Aquatic species compared to the very-short term (table 5 and fig. 2), notably because the lateral and vertical connections, the substrate of the bed and discontinuities would be restored naturally. For terrestrial species and habitats, only scenario 3 mitigated the impacts of the works. This scenario would allow the development of wooded vegetation, which will eventually shade the riverbed, an important feature for the fish population, and produce dead wood essential for some insects (Rosalia alpina). The two other scenarios (1 and 2) still had negative scores because they entail removing the tree canopy layer, involving a decrease in shading and subsequently the absence of dead wood. The medium term analyses confirmed that the scenario 1 may have a negative impact on the terrestrial environment since the "high tree" layer will not be replanted, following the recommendations of French technical guides (Vennetier *et al.*, 2015), (Evette *et al.*, 2014). Conversely, Scenario 3 stand out clearly with a rating of 3.8 corresponding to an overall positive development impact. Especially for aquatic species such as Austropotamobius pallipes, since river bed enlargement should reduce flow speed and create over time a calm zone favorable for this species. The good balance between the evaluations of the aquatic and terrestrial environment shows that scenario 3 is adapted to the plurality of the riparian environment and to the diversity of the fauna and flora of this dike section. The values of the Scenario 2 seemed relatively neutral, as an identical dike renovation rather than a new development.

3.3 Final decision of the development choice

The aim of the last phase (Steps 4 to 10 in Figure 1) is to reach the final decision for the development works. The preferred scenario is that which has the most positive (or at least less negative) impact on selected species and habitats (GEATHS) in the medium term.

Two situations can be encountered:

- if, following Step 4, the potential effects of the "preferred scenario" seem not significant or favourable for the ecosystem, then the process stops and the preferred scenario is chosen (Step 5 – red arrows in Figure 1);

- else, improvement measures must be proposed (introduction of fascines, construction of a fish pass, plantation of vegetation buffer strips, etc.) to enhance the scenarios. A new loop in the method is implemented (green arrows in Figure 1 – Steps 6 to 10), which takes these improvements into account. The new scores are calculated (Step 8-9) and the scenarios compared again. The process stops after one or several loops, when the best modified scenario, considered as acceptable, is chosen (Step 10).

For example: if a scenario foresees the complete levelling of a dike, then the indicator "run-off from agricultural zone" for "the very-short term" will be assigned to it and it will be assessed at -10 for the aquatic environment. This run-off will lead to a highly negative effect on fishes and crustaceans. Therefore, these indicators for the "very-short term" will be quoted -10 for fishes and crustaceans. However, an improvement measure can be introduced in the scenario by adding fascines or planting buffer strip that will limit agricultural pollutants and erosion inputs. This will allow changing the indicator scores for fishes and crustaceans from -10 to 0.

Finally, the SMIGIBA team chose scenario 3. As the scores obtained with this scenario were favourable, no improvement measures were proposed (cycle shown in green in Figure 1). A new assessment of the impacted territory will be carried out after 2 years to check our results and adjust them if necessary, by scenario improvement measures. Likewise, this monitoring will be carried on by comparing expected and actual values obtained in situ after 8-10 and 15-20 years, refining the scores given to the indicators at each time phase. This will enhance the forecast of long-term impacts of such developments. In case of a significant difference between predicted and actual values, the scenario will be reconsidered in order to reduce the impacts generated by future similar works.

4. Discussion

Our method is a "fast first level" assessment of the impact of development scenarios. According to experts or managers, it is easy to appropriate and it allows developing a multidisciplinary interactivity around a development project. Most of the methods previously proposed (Haury et al., 2006; Carnino, 2010; Bensettiti et al., 2012; Viry, 2013; Gayet et al., 2016, Devillers et al., 1991; Ormerod et al., 1993; Bryce et al., 2002; Brin et al., 2009) use significant amounts of measurements, concerning either the aquatic or the "forest" environment and require studies carried out over a longer period with more staff. Conversely, our method does not directly use instrumental measurements, nor accurate investigation on species. It allows choosing between different scenarios and pursuing the study with only the most suitable one for the territory. This significantly reduces the cost of the study (one scenario is investigated in detail instead of three in our case study) and optimizes the short time available when urgent decisions are required. However, depending on the importance and the nature of concerned issues (e.g. are human lives, huge potential economics or environmental damages or endangered species at stake), more in-depth investigations should be planned rapidly to validate, improve or later reorient the works and developments.

Compared to expert based opinion, our method relies on knowledge formalization that improve largely the robustness of the assessment as indicators are identified and described by a grid. This grid allows obtaining the information necessary to correctly use the indicators and achieve repeatability and reproducibility of the assessment. In the same vein, the aggregation methods are explicit: this leads to more robustness, indeed the results are comparable from a site to another or a scenario to another.

In our case study, and thus the first design of our method, we only considered three time spans up to the medium term (~ 20 years), addressing the notions of resistance, recovery and resilience for the key elements of the targeted ecosystem. These time spans must be adapted in each case to concerned issues and available knowledge. In rapidly changing territories (periurban areas, developing countries), no long term or even medium term forecasting may be possible. In protected or agricultural areas far from towns, as far as forest ecosystems or long-lived species are concerned, 20 years may be too short and a real long-term assessment may be usefully considered (Hupp, 1992, Newaz et al., 2019). More generally, the comparison of scenarios must take the potential evolution of their impacts with climate and global change into account. Time spans must be carefully chosen according to the uncertainties related to these evolutions.

In our case study, we only took the area directly affected by the potential works into account, and species locally present at least at some seasons. But many species may be impacted on a larger scale by side effects or remote consequences of the proposed scenarios, particularly migratory species (e.g. fishes and birds) or any plant or animal depending on the ecological corridor along the river to move or disseminate.

Our method mainly relies on the assessment of indicators that are combined through the mean operator to provide global results. For this first version, it was decided not to assign variable weights according to the environment (aquatic or terrestrial), species or habitats or anthropic constraints (recreational activities, agriculture, navigation, etc.). We chose to use the raw mean but a weighted mean could be recommended if an endangered species or a rare habitat were at stake. An assessment of the territory is planned 2 years after the end of the works corresponding to the transition between “very short term” and “short term”: if a species or habitat is more impacted than what was predicted, it may be relevant to give it a higher weight in the assessment to define new corrective actions and improve the chosen scenario in the future..

As all the methods based on indicators (Wu et al., 2015; Forio et al. 2017; He et al., 2000; Yates et al., 2014; Meyer, 1997; Nakamura et al., 2006; Brauman et al., 2007; Vidal-Abarca et al., 2016; Martin et al., 2018), the robustness of our approach depends on the reliability and accuracy of these indicators. Some indicators can be robust because they stem from preexisting local studies, for example in the framework of the creation or labelling of classified territories (natural reserves and parks), or from previous development works or assessment of natural risks. Other indicators should be less accurate. The use of existing models should improve the assessment process: models of population dynamics for endangered species, models of ecosystem dynamics for a key habitat, or hydraulic models (e.g. for water speed and depth, flood risk or run-off. Nevertheless, it would be very impossible to use a "general model "for the full assessment of a scenario, which combines a wide variety of physical, chemical and biological indicators. Thus assessing first the reliability of indicators should be an important step before their final choice and number. This may help looking for additional information or skills, and later define new studies required to firm up work impact assessment. A weight could also be given to indicators according to their robustness and accuracy.

Our method relies on the knowledge and experience of experts (Merad (2010);(Leduc and Raymond, 2000). These experts should preferably have crossed skills: this makes the exercise more robust, each one being able to adjust his proposals to others for an integrated expertise rather than just a "juxtaposed sum of skills".

Finally, our method mainly relies on expert scientific and technical knowledge, but local knowledge and skills can also be used to complete the information. The synergy achieved between scientific and local knowledge is increasingly acknowledged (Bélisle et al., 2018):

local people such as those belonging to NGOs and anglers have environmental knowledge stemming from day-to-day contact with the territory. They can provide information on the species present in a particular area, the increase or decrease of a population, and ecological and biological characteristics. This can be of major importance in the case of territories or countries where scientific knowledge is lacking.

Furthermore, our method is simple and explicit, the results and figures obtained can be adapted to the general public. Thus the method can provide a good communication tool. It is even possible, in the case of a species or habitat giving rise to controversy, to integrate it specifically in the study to prevent conflicts

5. Conclusion

All watershed managers are faced with the difficulty of choosing between several development scenarios. The methodology proposed in this article aims at providing objective help for rapidly identifying and evaluating effects on the biotope that may be induced by a development project. It is based on three temporalities (very short, short and medium) and, ideally, is capable of reducing the negative effects of such development projects.

It is important to emphasize that our method do not seek to reach a state of optimal naturality (Peterken, 1996), or to design biodiversity indicator (Larrieu *et al.*, 2012; Emberger *et al.*, 2013). Moreover, outputs of this method cannot, under any circumstances, neither allow to bypass the regulations on nature protection, nor replace the statutory environmental impact assessment when protected species and habitats are at stake, or the design of possible compensation. Thus the indicator values should be considered as trend indicators and not as an absolute score. It should be borne in mind that the results and this method cannot replace specific scientific studies in situ or in the laboratory.

However, our application can be used to gain better and more global insight into the specific problems of rivers and riparian zones. But it can be implemented more broadly for any other type of ecosystem facing urgent issues and works, and at different scales

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