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River Management & Restoration: What River Do We Wish for

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Abstract: In this paper we propose a new framework to support river management and restoration in a more effective way, both conceptually and operationally, in view of an increasingly challenging future. 'Development' almost inevitably leads to modifications of rivers. These modifications are governed (at best) by planning exercises which typically encompass multiple and generally conflicting objectives (whether explicitly or implicitly). To address the inherent conflictual nature of a decision problem, it is key to measure the degree to which the objectives are (expected to be) met. This requires that suitable evaluation indices are established and assessed. To this purpose, we point out the important role of the Value Function technique inherited from Multicriteria Analysis. One of these objectives is the "Natural value N" of the river. We notice that a lot of ambiguity exists regarding its definition. To clarify this point, we develop a reasoning that makes it possible to structure and assess it in a conceptually sounder way, while clarifying the role of the two leading concepts: the *Reference Conditions* and the *Leitbild*. With regard to the relevant decisions involved, the delineation of the fluvial space, together with the improvement of the water quality and hydrological regime, represent the key issues that a decision making process should address, particularly thinking of the expected consequences of climate change. We propose henceforth a pragmatic, structured, adaptive planning framework which harmonizes all such concepts. We believe that this proposal may provide a useful contribution to improve and optimize river management and restoration.

Keywords: multi-objective planning; river restoration; *Reference Conditions*; *Leitbild*; indices; fluvial space

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1. Introduction

The number of free flowing rivers has dropped dramatically over time. Nilsson [1] had already noticed this trend 15 years ago. Today, [2] observe that only 37% of the rivers that exceed 1000 km remain free-flowing along their entire length; Belletti [3] estimated the presence of more than one million barriers in EU rivers. The anthropogenic manipulation of river configuration (morphology, geometry, and the set of mechanisms for control and exploitation) is to some extent unavoidable and no doubt will increase in the future. Rivers are important environmental assets which belong to the category of common goods. In a number of situations it is possible to effectively manage similar types of shared resources (the "commons", as identified by [4]) through consolidated mechanisms conceived and implemented by the users themselves as a recognized community, as opposed to the two mainstream management approaches in environmental economics, i.e., either centralized governmental control, or the "free market" based on well-defined property rights ([5]; interesting examples are also presented in [6]). However, the pace of change of our world calls for increasing governmental intervention, whether to coordinate different parties or to actually drive, and intervene in, decision making. In the best of cases, a new river configuration is the fruit of an informed, participatory planning process where deliberation matters [7,8]. This exercise always involves multiple objectives, whether explicitly or not. One of these objectives is the "ecosystem integrity" (or *health*) or, more generally, its *natural value* (referred hereafter to as the "N" objective, N standing for Nature). With N, a non-use value is associated (an existence, altruistic or philanthropic, bequest or legacy value) [9–12], and several attempts have been made to measure the N value in economic terms (e.g., [13,14]).

Other objectives are typically involved: these can be labelled "fundamental" objectives in the sense of [15] as they play an active role when a balance of pros and cons is searched for. In some case synergies may be found within these objectives; for instance, [16] argue that in the UK compliance with the Water Framework Directive (WFD, DIR 2000/60/CE, which promotes an integrated approach to achieving "good status" for all European waters (https://ec.europa.eu/environment/water/water-framework/, accessed on 3 August 2020), would help to meet the Flood Directive requirements (DIR 2007/60/CE). However, in general, fundamental objectives conflict with each other; for instance, in several cases flood control is still pursued via hydraulic works which definitely do not harmonize with the criteria of the WFD, as argued by several river restoration stakeholders (e.g., CIREF, Centro Ibérico de Restauración Fluvial, the Iberian Centre for River Restoration, www.cirefluvial.com (accessed on 3 August 2020); and CIRF: Centro Italiano per la Riqualificazione Fluviale, the Italian Centre for River Restoration, www.cirf.org, accessed on 8 May 2021). With such objectives, several pieces of (direct, indirect or optional) use values are associated which correspond to provision, regulation or cultural ecosystem services. This discussion, together with the identification of fundamental objectives developed later, points out that, even when all uses and ecosystem services are accounted for, the river itself still calls for a specific objective: "N". Implicitly, this is what the WFD has asked for and, more or less clearly what all River Restoration (RR) projects aim at. However, RR and river management in general are still permeated by a certain degree of confusion precisely because, on the one hand, the multi-objective nature of the underlying river configuration planning problem is neither recognized nor addressed, and, on the other, because "N" can entail quite different and mixed views.

In this paper we concentrate at first on this latter issue by critically pointing out a number of aspects related to the conceptual meaning that should be associated with the N objective. Hence, we focus on its structure, which involves discussing the Reference Conditions concept (amongst others). We then gather the ideas seeded in that discussion to depict a logical, operational framework centered on a multi-objective approach that in our opinion may drive better choices, i.e., recognizing transparent trade-offs within an adaptive framework, relevant in a quickly changing world. This effort is in agreement with the words of ([17], p. 30) " … *unless sound conceptual frameworks are developed that permit the river network scale ecosystem services of river rehabilitation to be evaluated as part of the process of river basin planning and management, the total benefit of river rehabilitation may well be reduced. River rehabilitation together with a 'vision' and framework within which it can be developed, is fundamental to future success in river basin management*." However, while they propose a kind of mechanical scoring procedure to prioritize potential actions (particularly conceived to deal with hydrological networks), we stress the importance of identifying and measuring all individual objectives (including those linked to ecosystem services) to evidence their conflicting nature and find explicit trade-offs, through dialogue and negotiation.

This is not a "classic" research paper (which entails a methodology, a result and a discussion section); nor is it a review paper. This paper rather presents a critical, eclectic and original rationale which looks for weaknesses and strengths, and proposes a conceptually satisfactory harmonization of these that, in our view, may contribute to achieve the main purpose of improving rivers and, with them, human quality of life.

2. Review and Discussion of Key Concepts

2.1. Riverine Ecosystem: What Matters to Us

In this section we discuss what counts most to "us", as humanity, with regard to the river ecosystem in terms of its non-use value. We argue that the current approach, which adheres to the WFD concept, shows conceptual flaws and some practical weaknesses.

2.1.1. Life First of All?

The biotic component, particularly the fish population, is very often considered that which really matters in terms of nature conservation and restoration. Indeed, we regard water quality, water regime, and longitudinal continuity as essential components in sustaining a fish community in good health. Even riparian vegetation and geomorphic processes are seen as instrumental factors in creating habitats and fostering rejuvenation to support life, i.e., mainly fish. The WFD has somehow enshrined this idea on the assumption that what really counts is the biotic component, while all the rest is basically functional (see the Júcar case in what follows). However, this position is not always convincing. For instance, when the morphology of a high mountain stream is anthropogenically altered, we may feel a sense of aversion even if no uses are involved, nor even any fish population (naturally absent), but because the alteration affects a pristine asset.

2.1.2. Geomorphology First of All: Not Quite!

At the other extreme, some (e.g., [18]) regard the morphological component as a priority. Geomorphic behaviour and evolution indeed determine (together with geology, lithology, hydrology, the set of works, etc.) the physical structure of the active channel and its interaction with the fluvial corridor and the floodplain (as stressed for instance by [19]), hence the presence of habitat and, finally, of life. However, we can the notice that the morpho-dynamics is in turn influenced by the biotic aspect through riparian vegetation and its dynamics (e.g., fall of trees generating avulsion), but even in more subtle and indirect ways, through the de-stabilization of banks because of animals (e.g., river rats, *Myocastor coypus*, excavating their shelters), or even in more fascinating ways as when salmons migrating upstream are captured and partially eaten by bears, their remains being spread across the fluvial corridor, so enriching it with nutrients otherwise absent: this fosters the establishment of important riparian and floodplain vegetation, which in turn has a role in morphological evolution [20]. The acknowledgement of an inseparable and highly significant link between geomorphic and biotic processes actually pushed [21] to propose the new term "biomic river restoration".

In summary, it must be recognized that geomorphology and biota are both fundamental components, yet they are so interlinked that it is not possible to state which one is more important. The same holds for water quality and the remaining components. It is hence correct to affirm that several aspects do count at the same time: water quality; water regime; morphological configuration at the macro and meso scales; presence/absence, abundance and structure of aquatic animal and vegetal micro and macro species; composition, diversity, structure and health of riparian and corridor vegetation; presence of native terrestrial, herpeto and avifauna linked to the river corridor, etc. All these components are strictly interrelated, yet each one merits attention not only as a "causal factor", nor just as an indirect information vehicle (bio-indicator).

Some may argue that a more ecologically based point of view would rather look at "functionality, biodiversity and capability to react to external stimuli with resiliency and adaptability to changes" [22]; but this is slippery ground, as anthropogenically altered systems may often be superior to their natural counterparts, exactly from this perspective. In temperate mountain regions, as an example, the transformation of pristine forest caused by agriculture and cattle rising activities has fostered diversity of habitat and induced a growth in the richness of species, one of the attributes via which biodiversity is measured [23].

2.1.3. Restoring longitudinal Continuity May Bring No Benefits: The Case of the Júcar River

(This case study is inspired to the mission report conducted at the Confederación Hidrográfica de Júcar (Valencia, Spain) by Andrea Nardini and Jukka Jormola in 2015 for the EU project "Peer Review" of river restoration actions, coordinated by the MEditerranean Network of Basin Organizations (MENBO)).

The Júcar case shows how the WFD evaluation structure may lead to inappropriate choices, which motivate an alternative approach. In this sense, it is representative of the dilemma of many other EU institutions in an analogous position.

Very 'schematically, the position of the Confederation Hidrográfica del Júcar ("Júcar RBA", River Basin Authority)—as presented ahead of the Peer Review mission in 2015—can be described as follows:

- Aim: to improve the fluvial ecosystem (at the same time satisfying other needs, particularly water uses)
- Hypothesis (and conviction): enhancing longitudinal continuity is «good» (an Artificial Neural Network model developed by [24] for fish species richness supported this conclusion)
- Task: to prioritize amongst potential interventions (already identified) those that appear most likely to meet with (demonstrable) success
- Practical–strategic problem: how to ensure «success»?

Júcar RBA implicitly adopts the value tree [7] in Figure 1 (top), which is essentially consistent with the WFD approach. Its associated evaluation structure can detect, in principle, improvements (or worsening) of overall status due to each individual component (water quality, Hydro-Morphology-HyMo, biota); however, the vision undoubtedly is "biota at the center". Many may share the philosophical position that the enhancement of the biotic component, particularly that of the fish fauna, is the true objective, while improving the other components is the means. This may lead to an interpretation of the value tree as a cause–effect relationship, i.e., improving water quality and/or HyMo would lead the biota component to improve consequently and, with it, the overall WFD index.

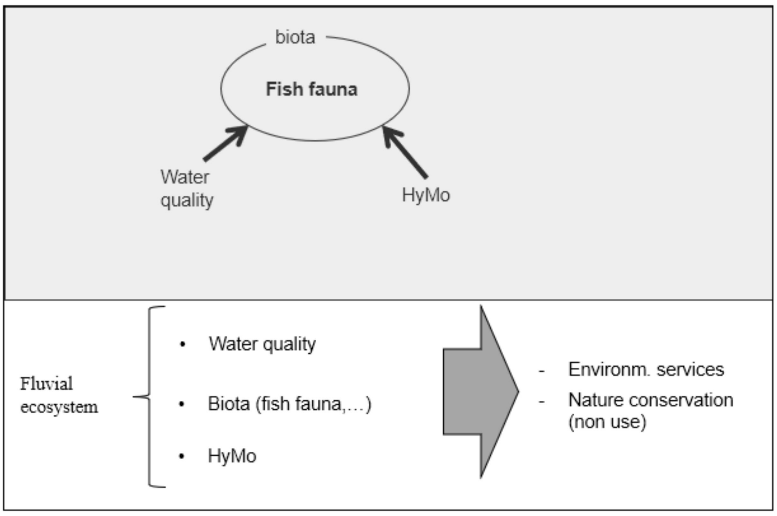

Figure 1. (**Top**): value tree adopted by the Júcar RBA in full agreement with the WFD ("HyMo", Hydro-Morphological component). (**Bottom**): The corrected value tree for fluvial ecosystems where all three components participate in determining the overall ecosystem health (see text).

In practical terms, as detailed below, it must be recognized that there is a serious risk that the improvement of the water quality or HyMo components (e.g., through a better longitudinal connectivity) may bring in reality no visible improvement in the overall WFD status quality index. As such, a barriers removal measure (HyMo) may fail to reach the ultimate objective.

This is in general (independently from the Júcar case) because of technical issues, on the one hand, and physical issues on the other:

Technical Issues:

(i) The HyMo component according to the WFD construct does not even come into play when the general status is less than "high"; so its improvement may be transparent in terms of the overall status assessment;
(ii) The "worst case wins" structure of the status assessment adopted by the WFD (see Section 2.5) may freeze the scoring, even though a component is indeed improving;
(iii) A physical improvement may be not sufficient to make the discrete WFD classification make a jump into a higher class.

Physical Process Factors:

(a) The biotic status may not improve because of several other negatively affecting causal factors. The structural longitudinal connectivity (or continuity), an important subcomponent of HyMo, is indeed just one of several causal factors which influence the status of the fish fauna population (Figure 2): re-stocking for sport fishing and the alteration of water regime (very low flows or loss of due variations because of extractions, or hydropeaking due to electric reservoir management) are the key factors in many reaches. The riparian vegetation plays an important role too (shading, supply of organic matter, habitat, etc.), along with other factors.
(b) In addition, an improvement of longitudinal connectivity may even induce a negative effect, because of allochthonous species that may spread more easily.

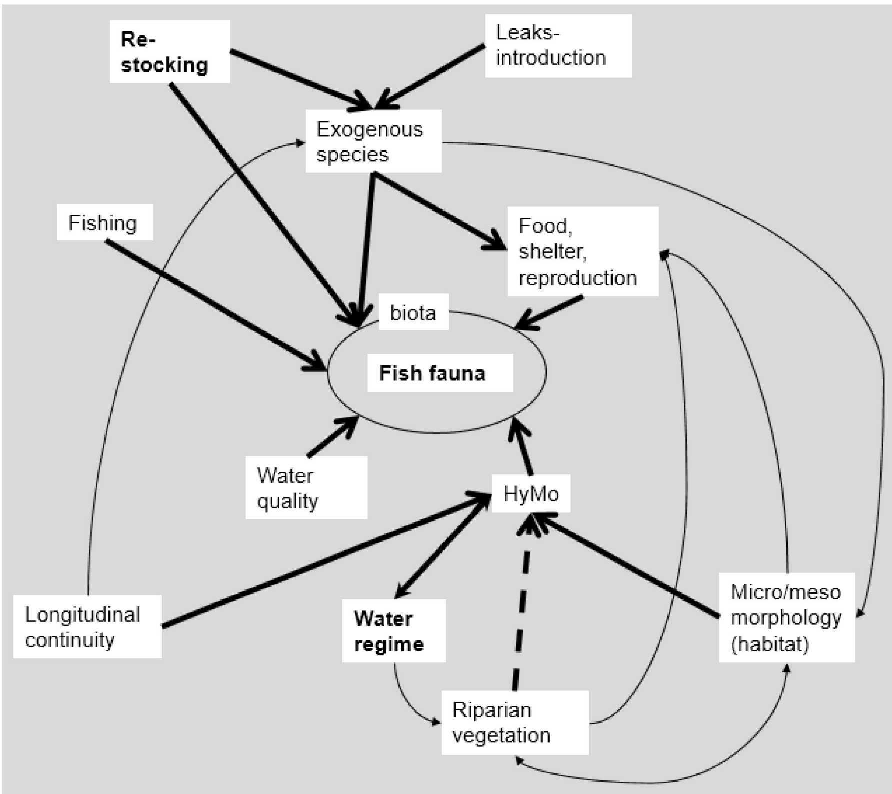

Figure 2. The cause–effect network for fish fauna, not to be confused with a Value tree which is a hierarchical organization of the reasons why a factor is considered important by some stakeholder (see [7] for a discussion of this difference; in [25] a more practical perspective can be found).

If instead we switch from the original WFD position to a more balanced vision, with a value tree where each component deserves its place at the same hierarchical level (Figure 1, bottom), and, in parallel, we adopt for the overall index an aggregative structure other than 'worst case', this problem can be solved. Indeed, under such a position, it is possible to state that the improvement of just a single component (e.g., Biota, water quality or HyMo) leads to an overall improvement. Hence the project may prove 'successful' even when, for instance, just the HyMo component improves.

This statement might sound trivial, but it is particularly relevant from a management point of view: a Authority like the Júcar RBA might decide to stop its program of longitudinal continuity restoration if no demonstrable success is ensured; on the contrary, it might continue with it if a different assessment structure for the status were adopted (and no allochthonous species invasion were induced). It has to be noted, finally that concerning the specific case of Jucar basin the study by [24] may seem in contradiction with our reasoning as it concludes that the removal of some weirs would improve the native fish species' richness. However, although very well developed, this is just a model, and as such it is inevitably affected by a number of limitations, as recognized by its authors. For instance, amongst others, their regression (an ANN) -based on field data- finds that the key morphological variable leading to a native species increase is the frequency of riffles (a habitat factor), but the link between the removal of weirs and such an increase in riffles is just a conjecture (actually, it is treated with a sensitivity analysis); longitudinal continuity itself, contrary to what one would expect, has a minor effect on the species. Furthermore, inter specific competition and the possible invasion by allochthonous species are not considered so that it may prove to be not adherent to reality for several of the reasons mentioned. Furthermore, in general, even if the fish component actually improved, the WFD index would not necessarily, because of the technical arguments presented above on the very structure of the WFD evaluation approach. More important, independently from the specific Júcar case, which is here used indeed as a pretext for illustration purposes, our key message is that overlooking the intrinsic importance of components other than biota may distort a restoration policy

2.2. Ecological Status or Trajectory

We argue here that we are indeed concerned with a whole state trajectory of our fluvial ecosystem. This position conceptually solves a number of issues that have fed extensive discussions in the literature.

2.2.1. Forms or Processes

A river is definitely not a 'static' object; it is not enough to merely consider its forms (including the structure of its biotic communities) because processes also count, both for conservation purposes and for the exploitation of its environmental services (take for example the transformation of organic pollutants into mineralized compounds; [26]). On the other hand, it is somehow misleading to emphasize processes (e.g., solid transport, ecological functionality, bio-geochemical cycles) as if they were the most important factor as far as the ecosystem itself is concerned. Processes eventually lead to a sequence of statuses (e.g., physical configuration, presence of certain morphological units, habitats, species, populations, individuals, genetic stocks, etc.), i.e., to an evolving assemblage of "forms" in a broad sense, a kind of "somatism of nature". In this case, varying somatism is inseparably associated with exchanges of matter and energy (starting from water flows) and with biochemical information within the river itself, but also outside it, as it comprises its riparian zones and floodplain, and even the whole basin with its interacting atmosphere which brings gaseous compounds, solid nutrients and eliminates residuals. So what counts is both the sequence of states and the underlying processes. Conceptually, both can be captured by considering the whole 'state trajectory', i.e., the sequence of states along a significant time span, all states being dynamically related to each other. Indeed, this sequence can take place only if accompanied by the associated processes which are at the same time a "cause" of future states and a "consequence" of the current state. Indeed, if we consider fluvial geomorphology, processes (amongst others) of solid transport, erosion, deposition, removal and resettlement of riparian vegetation and associated woody debris, together determine a given fluvial configuration (e.g., braided) that would not otherwise occur in that given context. An analogous discourse holds for the geo-biochemical and biological spheres with regard to the transfer and transformation of nutrients and other compounds, as well as for living populations.

2.2.2. State Trajectory and Its Challenges

From a conceptual point of view, we are interested in the whole state trajectory because we aim to express a global judgement over a suitable time interval, exactly as we do with an economic evaluation by aggregating future costs (and benefits) through the summation of discounted values. From a practical point of view, in addition, it is clearly much easier to measure forms rather than processes. It is hence more logical and honest to refer to the former, making sure we take into account the whole set of forms that are able to capture the processes considered relevant. Emblematic in this regard is the exercise conducted by [27] who compare different approaches to geomorphic classification including those based purely on forms and those claimed as 'process-based'; substantially, the announced divide vanishes.

The assessment of a whole trajectory, however, is not easy to implement operationally as one would need a prediction model for the (interrelated) morphological and biological time evolution (related challenges are expressed for instance by Schiemer, 2015); in addition, the whole river network should be considered (in principle) because reaches are interlinked. Attempts at prediction concerning the geomorphic component exist, ranging from physically based—e.g., [28]—to semi qualitative ones, e.g., [29] or [30]. Another difficulty which affects this idea regards an essential conceptual point: which factors should be considered? Should earthquakes/eruptions be taken into account? Which time horizon? Furthermore, time aggregation raises some conceptual and practical difficulties: which criterion to adopt? How to deal with the multiple dimensions of the state? Still, plausible choices can be found. As far as time aggregation is concerned, for instance, the most commonly used approach (although rarely made explicit) for the sake of "strict sustainability" [31], consists of referring to a 'final state' sufficiently far away in time so as not to worry any longer for some time to come. This position (which corresponds to an intuitive interpretation of the discount factor) makes us accept the "transparent" nature of the "far away in time" expression. An alternative interpretation is to assume that everything remains substantially the same, i.e., that the system has reached an equilibrium (even if it may possibly never achieve this, because of a too slow dynamic or because new factors may emerge). This position can be acceptable, yet we must be mindful of it.

2.2.3. Status or Causal Factors? The Dentist Syndrome

Rather than making explicit the above trajectory discourse, it is usual to fall into the temptation of incorporating, amongst the attributes, descriptors of causes that may modify the future fluvial ecosystem configuration. These are taken into account while expressing a current judgment today, and hence may be weighed negatively as they may lead to a future undesired status.

For instance, as regards the geomorphic component, it happens in HYMET (the Hydro Morphological Evaluation Tool, proposed by [18]), as well as in IDRAIM-IQM proposed by [32] (IDRAIM, "sistema di valutazione IDRomorfologica, AnalisI e Monitoraggio de corsi d'acqua", i.e., system for the hydro-morphological assessment, analysis and monitoring of water courses; IQM, "Indice di Qualità Morfologica", or Water Quality Index), where the presence of works that can alter the morphological dynamics and hence alter the river configuration is weighed negatively. This position has an inconvenience: it is no longer clear how much we are concerned about the status presently displayed by the ecosystem rather than how much we fear worse states in the future. It is like when one starts to feel sick before going to the dentist just because he is afraid to feel pain there; this can cause anxiety and even suffering, while the dentist treatment might eventually result in a pain free state.

HYMET assumes that, if a closed basin at the initial section of a fluvial reach is in bad geomorphic condition (because it supplies a reduced solid flow with respect to a nonaltered condition), then that fluvial reach must also be considered to be in bad condition, independently from its intrinsic, present status, because at some future moment that deficit is expected to rebound on the reach itself. However, thinking pragmatically, that deficit may produce some manifest effects on the reach either in a time too far to worry about, or perhaps never, because in the meantime many events may occur (for instance the sediment supplied from a landslide which is not visible today, or the river adapting and absorbing the supply deficit without diminishing its value), or just because we might have made a wrong estimation (not a rare possibility when dealing with solid supply). An index built on this conceptual basis will lead to an incorrect lower scoring and is blind to factual reality: the fact that the considered reach is at present, for example, in a very good shape.

From a managerial point of view, an index of this type might inhibit any restoration action at the reach or corridor scale because no increment of the index is gained, analogously to the Júcar case.

2.3. From "Health" to "Value"

In order to assign a value to a (fluvial) ecosystem besides its "health", it is necessary to consider another aspect: "how special it is", i.e., its peculiarity. This can derive from bio-geomorphic characteristics, for instance a spectacular gorge carved between amazing vertical walls; waterfalls; rare forms sculpted in the rock; the outcrop of rocky formations; the presence of unusual vegetal or animal communities which give rise to surprising shapes, colors or behaviors (e.g., the famous Caño Cristal, in Colombia: Figure 3). A positive peculiarity can even be due to aberrations from "natural" status: for instance, some areas along a river (perhaps artificial ones like former sand and gravel mining sites) may become a new—or even the only—rest site for important bird migratory species after their original environments have been profoundly altered or even destroyed.

Figure 3. El Caño Cristal (La Macarena, Dep.tp Meta, Colombia) (source: http://www.cano-cristales.com/, accessed on 8 May 2021).

The non-use value must consider this aspect (Figure 4). In such a way, when evaluating an impacting project, it will be easier to assess whether the overall benefit really outweighs the loss of value of the impacted ecosystem.

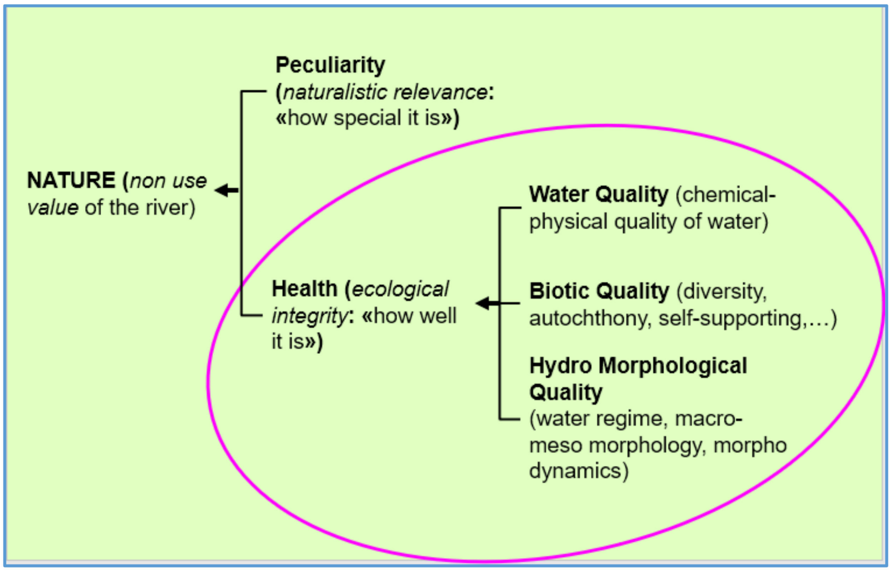

Figure 4. The non-use value tree for a fluvial ecosystem: in addition to "how well it is" (*health*), we must also consider "how special it is" (its *peculiarity* or *naturalistic relevance*).

2.4. The Reference Conditions (RC): A Dead Concept?

In this section we discuss a very controversial point related to the Reference Conditions (or Reference Situation, or Reference State; "RC" in what follows), a key concept of the WFD: in fact, all the metrics used to assess the "Ecological Status (ES)" of a water body (high, good, moderate, poor or bad) are intended to assess the gap between the present conditions of the ecosystem and its undisturbed Reference Conditions. The RC concept has been criticized by robust arguments on numerous occasions, and a different approach—the Leitbild– (which specifies a desirable status rather than the RC) has been deemed to be more appropriate [33]. In what follows we argue why the Leitbild alternative, seemingly attractive, is however dangerous because it leads to artificial and fragile systems; in addition, it is ethically refutable and even conceptually incorrect because, as a matter of fact, it represents a trade-off that has not been chosen explicitly. We conclude therefore that, although undoubtedly affected by several weaknesses, the RC concept is still necessary and that there are practical ways to make the best of it.

2.4.1. How Can We Measure "Health"? A Relative Perspective for an Absolute Judgment

The scientific community paradoxically does not find any other way to measure ecosystem health in an absolute sense than by applying a relative perspective: satisfaction is maximum when all the adopted attributes lead to a situation that fully meets the "RC" (this is the WFD approach).

It is quite obvious to regard the RC as the "natural state". As pointed out by several authors, however (particularly [33,34]), the "natural state" definition has substantially no sense for the following reasons:

(i) We are unable to define what "natural" means in practical terms, as all too often pristine reaches no longer exist (unless for minor water courses); on the other hand, it is even more questionable to refer to the *"original state"* because almost everywhere (particularly in Western Europe as well as in Asia and in Southern America) territories—and rivers—have been heavily altered since ancient times (in EU back to the Roman empire and even before). Perhaps, it makes sense in countries like Australia and New Zealand where a "pre-colonization" phase is clearly distinguishable and can be labelled as the "original status" [35], although, strictly speaking, in New Zealand the Maori contributed in important ways to modifying the territory through large wood fires from 700 years ago (https://en.wikipedia.org/wiki/History_of_New_Zealand#M%C4%81ori_arrival_and_settlement, accessed on 6 May 2021). It is even more dangerous to restrict the analysis to the management time scale (last century only) because we would rely on a legacy of heavy alterations deriving from the industrial revolution with consequent widespread deforestation and hence (in particular in south-eastern France and north-western Italy) larger solid supplies, wider riverbeds, etc., compared to the "origins" [36]. Hence, that "before" would be quite far from "natural";

(ii) We are not even able to define what 'natural' means conceptually in a "clean" fashion, because everything fluctuates and evolves, displaying cycles, trends or even dramatic changes in river styles [37]; therefore, in order to define a specific status, we should choose a particular moment in time . . . which one though? Climate itself is indeed not steady, even in recent times and independently from anthropogenic influence (think of the little ice age [38]);

(iii) Finally, perhaps this unreachable "natural state" may no longer be desirable today from a purely environmental–ecological point of view because the context has profoundly changed and what was "natural" before may be intrinsically incompatible with today's climate, species, vegetation, lithology (and definitely with today's anthropic context). It is not surprising, indeed, that nowadays we often strive to protect habitats and ecosystems regarded as "natural" that in fact developed over time as a consequence of human intervention (reservoirs, abandoned mining sites that spontaneously re naturalized, etc.).

Summarizing, there is nothing that can be defined as "natural" for comparison purposes; the search for the "original state" as a kind of "paradise lost" may lead us to a mistaken point; conceptually, nothing is clear cut because everything keeps changing.

2.4.2. Leitbild: A Possible Solution, But Not at This Stage

It would appear then more attractive and sensible to define a new reference state which expressed our target image, a Leitbild [39–42], which is something we aspire to within feasible limits, such as a river typically characterized by a dynamic morphological equilibrium (a relative of "sustainability", because it ensures that the configuration keeps in time), by a desirable physical configuration (implying the least maintenance effort), by, of course, clean water and "right" biodiversity (including species we regard as "appropriate", such as the endemic and autochthonous, particularly if threatened species, and without the "bad" ones, i.e., the allochthonous or invasive). On top of all this, we envisage a spatial and morphological configuration that is compatible with both current and future uses (e.g., hydropower energy generation, water extraction for irrigation, occupation of space for anthropogenic settlements) and is able to face climate change (for instance to cope with harsher and more frequent floods and droughts).

However, this does not work either. A manifestly modified river, for instance downstream form a dam, may fully satisfy some stakeholders (see Figure 5) simply because they prioritize—although perhaps not explicitly—the cultural service of recreation such as sport fishing, linked to a direct use (denoted "S objective" in what follows), typically not attentive to the autochthony of the existing species, and by doing so they penalize in fact the N objective (Natural value), silently leading us, undoubtedly, very far away from the idea of "naturality". With this approach, paradoxically, we might judge a whole extensively "damned" hydrographic network (the "N") to be fully satisfactory.

Figure 5. A paradisiac site for fly fishing may be found even downstream of a dam. The Strawberry river (Uinta region, UT, USA; photo: Andrea Nardini) downstream of the homonymous artificial reservoir is indeed, from personal experience, a magnificent stream for fly fishing. Beyond the beautiful scenery, this is linked precisely to the presence of the dam: in summer, flow rates are increased (hence offering more habitat to fish populations than in natural conditions); excessive frequent floods are smoothed, hence ensuring less stress; water is cooler (because extracted from the reservoir bottom), sufficiently oxygenated and clearer (thanks to settlement of fine solids within the reservoir), so allowing a deeper penetration of solar light and, with that, a likely higher ecosystem productivity, beneficial to a consistent brown trout population. At the same time, the nutrient balance does not appear to have been significantly altered (in spite of the natural supply of phosphorous loads from its upstream basin and possibly thanks to restoration programs; see, for instance: https://extension.usu.edu/waterquality/files-ou/Watershed-information/Main/NR_WQ_2014-02StrawberryRiver.pdf, accessed on 8 May 2021), and the geomorphic impact is reduced, probably because both the sediment supply and the transport capacity have been reduced, in this way keeping a certain equilibrium [43]. This fortunate combination does not hold, however, for other rivers in the region, for instance the Duchesne river, significantly altered as shown by [44]. Notice that we do not claim that this quite odd situation be of general validity and notice, moreover, that we are not focusing on native species, which may be affected quite negatively (as demonstrated in other situations, for instance by [45]), but rather on a (non-native) species of great interest for sport fishing: brown trout.

Even if the *Leitbild* configuration was attentively managed so as to maintain the desired situation over time (possibly through costly interventions to ensure the continuity of sediments, fish migration, etc.), this would result in a high artificiality (of management too) and a threatening fragility, because systems depending on human action can at any moment fail should any of the introduced artificial elements collapse. Artificiality and fragility are definitely undesirable characteristics in absolute terms as they may present us with a steep bill in future that we (or our offspring) might not be willing or able to pay. In spite of our management efforts, a heavily modified system is very likely to evolve, over time along a non-foreseen trajectory (as our knowledge of complex natural dynamics is still limited) and may lead us to undesired, no-escape situations with additional, even very high, costs and bring additional artificialization in future (there are countless examples of similar situations in every country). On the other hand, it may lead us to paradoxical situations where for some aspects we would like to return to an "original state" (at least the one previous to the intervention), but not for other aspects, when some of these, although artificially created, have by now become socially accepted and confirmed as they satisfy new needs created by the alteration itself. An emblematic example is that of the famous Colorado river in the Grand Canyon of the U.S.A., very well described by [46], where in fact a discussion is presented about which Leitbild to choose (although they do not use that term explicitly). Fragility is clearly undesirable since it may lead to unwanted and sudden changes with dramatic consequences as has happened in so many cases (e.g., Figure 6).

Figure 6. After decades of mismanagement, today the Secchia river (Emilia Romagna, Italy), originally braided, is heavily incised (up to 12 m and even more) and in threat of breaking through the Pleistocene clay substrate with unknown consequences. The process seems unstoppable; indeed, over the years several giant weirs have been installed and then destroyed by powerful floods ([47,48]; photo: Marco Monaci).

More serious, the Leitbild approach disregards that ethical principle of nature according to which even the nonliving world deserves the right to exist, i.e., deserves respect. The Earth Law Centre's "Universal declaration of the river rights" (www.earthlawcenter.org/river-rights, accessed on 6 May 2021), already ratified by a number of countries, which assigns juridical personality (and hence rights) to a river as if it was a "living" entity, is a clear demonstration of how real this perspective is. Also worth recalling is the conception of rivers that indigenous people have had from ancient times (for instance, the Maori in New Zealand or the Kogy and Wiwa of the Sierra Nevada de Santa Marta in Colombia—see [49]). The Leitbild approach, as an alternative to the search for Reference Conditions, tends to completely overlook how things would be without the anthropogenic alterations; besides, it simply ignores the non-use value of the ecosystem. It has the presumption of fully understanding the natural world so as to be entitled to control and modify it at will without recognizing the inherent risks. Or in the words of Pope Francesco [50]: "*The intervention of the human being on nature always took place, but for a long time it has been characterized by just accompanying nature adapting to the possibilities offered by things themselves. It was a matter of receiving what the natural reality offered by itself, like lending a hand. Vice versa, now the interest is in extracting all what is possible by imposing the human hand, tending to forget or ignore the very reality of what stands in front of it*". The Leitbild solution, hence, proves to be unethical as well as not satisfactory.

Finally, the Leitbild approach as a substitute of the RC concept is conceptually wrong because it portrays a specific trade-off amongst the fundamental objectives at stake, a trade-off, however, that is not made explicit and hence is not the outcome of an aware, transparent and participated choice of the community. In other words, from a conceptual point of view, the Leitbild can be specified only after the trade-off is chosen, not before.

2.4.3. The Reference Conditions Concept: Often Demonized, Still Widely Used and Indeed Needed

Although heavily criticized, the Reference Conditions (RC) concept is adopted more widely than declared, often in an implicit way. For instance, the IQM [51] takes a distance from it, but then embeds it under the following definition ([51], p. 113): " . . . *the conditions of a reach in dynamic equilibrium, where the river develops the geomorphic processes consistent with its given typology and where artificiality is absent or does not alter significantly the dynamics of the water course at the reach and catchment scales* . . . ". This definition excludes dealing with rivers naturally aggrading, like the *fiumara* Amendolea (Figure 7), where a very different condition exists: its reference would rather be a "bed load regime, confined, transport capacity limited, naturally aggrading" reach. The IQM, furthermore, by adopting the RC definition, explicitly in some attributes and yet implicitly in others, reduces the transparency of the index and opens the way to inconsistency. The River Styles framework [37] offers an articulated and original way to characterize and classify river reaches. It comes up with an "open ended" classification as it does not try to fit rivers into pre-defined rigid categories, but rather it recognizes that each river reach is different. Furthermore, it encompasses characters of different scales (ecoregion, basin, landscape unit, reach, geomorphic unit) in a single holistic and illuminating picture at the river basin scale based on few, very significant attributes (the "procedural tree") (the same idea has been re-worked later by the REFORM project—[52]- but, as it stresses too much the need to look for time changes, it loses holistic synthesis power). This way it provides an intelligible characterization and classification which implicitly merges forms and processes harmonically, enlightening the behaviour of each reach. Finally, the classification output is not just a label; in fact, it is a specific and thorough description of the character and behaviour of each river reach within the river network.

However, the River Styles Framework approach is somehow incoherent as far as the RC is concerned: it starts by refusing the approach, because each river "is a different thing", but eventually it assumes that, given the main characters of a River Style (confinement, floodplain character, planform, bed material texture), typical forms and processes should be encountered (i.e., a specific status; [53] offers detailed examples in this sense). Therefore, the Framework assesses geomorphic health according to the level of deviation from the status displaying those features which, hence, implies that the RC is taken for granted.

Figure 7. The assumption that dynamic equilibrium is 'the target', as implicitly a priori by [18,51], can lead to no escape situations: for instance, what level of health should we assign to the Fiumara Amendolea, a naturally aggrading river? From an anthropogenic point of view, undoubtedly, that river poses serious threats (see [54]), yet from a nature conservation point of view, we cannot state it is in bad health, because that is its intrinsic nature, at least in a contemporary time scale. (Photo: Andrea Nardini).

2.5. Measuring the Objectives: Indices

In a planning process, vagueness and ambiguity are ever-present enemies. It is key, therefore, to rely on the accurate verbal description of the objectives considered to be informative. Only an explicit conceptualization and a mathematical formalization ensure, however, that we escape ambiguity. In other words, the objectives must be specified to the point where they become measurable.

Measuring the involved attributes is possible, even when they are qualitative and subjective [55]. It is also possible to aggregate several attributes into one evaluation index expressing a satisfaction degree by means of a multi-attribute Value Function (VF) [56,57]. It is possible to obtain an overall measure over space (and time) by applying the same type of tool (e.g., [58,59]). These measures must not necessarily be meaningful in absolute terms (i.e., physical or economic measurable quantities): it is sufficient that they be meaningful for comparative purposes (e.g., [15,56]).

With the aid of additional hypotheses and suitable techniques, it is also possible to translate most of the objectives into an economic value (see for instance [13,14,60]), although this implies varying reliability depending on the case addressed and it is to be considered always with a degree of suspicion.

However, building evaluation indices in order to measure objectives is a delicate issue: it may imply more or less hidden underlying management choices. The definition of their conceptual structure entails risks from the very beginning because of redundancy in the value tree, or the mixing of causes and states, or because factual information is not distinguished from subjective judgment. A frequent pitfall originates from the mixing of two separate concepts: (i) the assessment (e.g., the factual ecological status and hence the N objective); (ii) the prediction of its future evolution due to natural and anthropogenic factors, where models come into play. Another major pitfall may involve indices: i.e., lack of internal coherency. This locution (introduced explicitly by [61]) stands for the following concept: an index provides a single numerical value for any combination of values assumed by its constituting attributes (i.e., "situations"); the value judgment associated with any "situation" that leads that index to assume an equal value must be identical, that is, no situation should be preferred. The index that fulfils this property (mandatory, but hard to satisfy) is "internally coherent". Conversely, if in correspondence of two situations deemed to be equivalent the index assumes different values, it is "incoherent" (i.e., structurally wrong).

In the following section we analyze some of these issues to identify areas of potential improvement, obviously with no ambition to exhaust such a key, complex topic in the planning process. We do not propose any particular index, but rather we recall some requirements that all indices should fulfil. We also highlight the importance of the multi-attribute Value Function (already cited), as a highly useful technique that can be adopted to build any index. The discourse focuses on the N objective (particularly the ecological status in the sense of "health"); however, our considerations are generalizable to any other objective (see Section 3).

2.5.1. Some Pitfalls and the VF Potential Illustrated through the IQM

This paragraph develops around the IQM (Index of Quality Morphological), proposed by [32,51] to assess the geomorphic status of river reaches. We do not intend to criticize that work, actually very valuable from a geomorphic point of view; rather, we take advantage of it to introduce a discussion about typical weaknesses related to the evaluation indices that are manifested explicitly in that work as in many others. We also point out how the use of the Value Function approach can help greatly improve the output.

The conceptual structure of IQM includes the following macro-attributes: geomorphic functionality, artificiality and morphological change, further detailed under 25 sub-attributes and associated indicators. The computation of the final value, for which a great deal of information is required, implies the use of a specific scoring system. We observe that, firstly, there is the issue related to the Reference Conditions as already noted above.

Secondly, several attributes appear to be redundant, so most probably they can be reduced without affecting the quality of the information, thus greatly simplifying the analysis and calculation: some "key attributes" (carrying the maximum information) might be identified for instance through a Principal Component Analysis or through a Multiple Correspondence Analysis. Thirdly, the index structure incorporates a number of attributes related to the presence of artificial structures, thus giving rise to the undesirable "dentist syndrome" described above. Finally, the adopted scoring system is not transparent and does not ensure internal coherence: it is very difficult indeed to understand what its effect on the final index is (if not through an ad hoc sensitivity analysis) and what is the underlying reasoning for choosing those values rather than others (the relative importance of the attributes is very much hidden).

On the other hand, the approach based on the Value Function (VF) concept and tool offers several advantages:

- It clearly separates (Figure 8) the objective measurement exercise (feeding the indicators) from subjective judgments (leading to indices, i.e., VFs), thus having the advantage of factual information whilst ensuring a much more transparent and understandable process.
- In order to build an evaluation index, 'subjectivity' is unavoidable as it directly expresses the perception of a person, stakeholder or social group. Nonetheless, with the VF based approach subjectivity is confined within a very recognizable and transparent step of the process, i.e., the construction of a multi-attribute VF (for which, most often, one simply builds a set of much simpler scalar VFs and then elicits preferences to obtain a well-defined set of weights). A sensitivity analysis can then be performed in a straightforward fashion.
- The VF approach theoretically allows the production of an internally coherent index, while, on the contrary, this is not ensured at all when a scoring system is adopted. Concretely speaking, this requirement is in fact hard to meet, but at least adopting a VF represents a first step on the way towards this, provided suitable techniques are adopted to build it.
- Lastly, this approach is more robust conceptually, much simpler to develop, communicate and understand, and as such it is definitely more straightforward and "democratic".

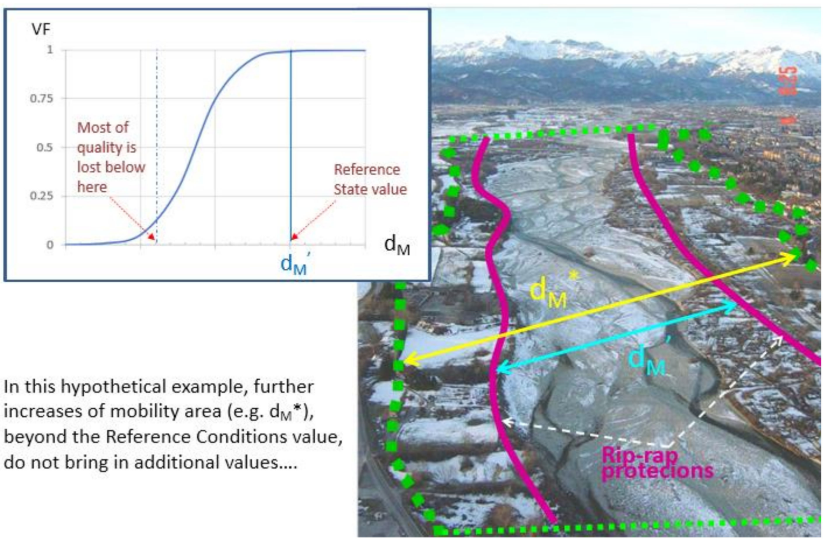

Figure 8. Example of a sub-index that assesses the mobility space (its "width"). The indicator on the horizontal axis is the area of the mobility strip. The reference value d_M' appears explicitly as a structural element of the scalar Value Function (VF) and corresponds to the adopted Reference Status (or, better, to its specific River Styles). Photo: PPT "Il fiume in Piena", Comune di Cuneo, Piemonte Italy (2004), with permission.

2.5.2. The Mathematical Structure of an Evaluation Index

Figure 9 shows a hypothetical, but emblematic, case where the aggregation criterion One Out-All Out (OOAO or simply "worst case") adopted by the WFD proves to be too rough and biased: in particular, it is not capable of detecting the improvements due to some of the components (in the example, the chemical and HyMo). In addition, as regards the HyMo component, it only takes into consideration two classes ("good or higher" and "worse than good"), which is not satisfactory as it leads to a binary judgement (yes or not), contrary to what is done for the biological component.

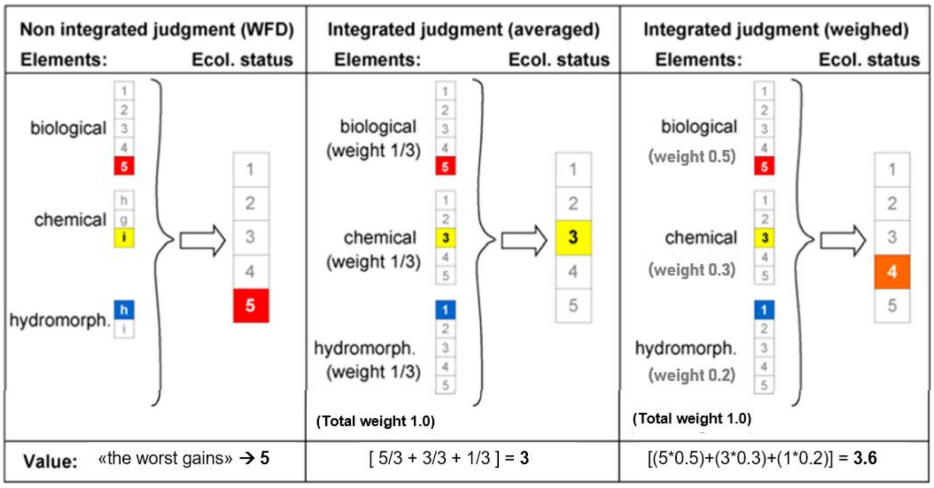

Figure 9. Examples of poor internal coherence through a comparison of different classification criteria for the ecological status. Left: the WFD criterion is "incoherent" because, based on the "worst prevails" dilemma, it produces the same value (5) and the same judgment ("bad") for the situation shown, as well as for other situations that are undoubtedly superior (e.g., chemical–physical elements in class h = high or g = good) or worse (e.g., hydro-morphological elements in class i = inferior). Middle: admitting compensation amongst attributes, and a weighted average aggregation with the same weights (1/3), the overall value obtained is 3 (moderate). Right: the same approach, but with different weights (0.5 for the biota component, 0.3 for the chemical-physical, and 0.2 for the hydro-morphological), produces a slightly higher value that leads to a higher quality class (4). (Courtesy of the Italian Journal *Biologia ambientale*; original author Giuseppe Sansoni).

It is be noted that in both weighted average cases (middle and right in Figure 9), the variation of any component is reflected in the final index value and the worsening of one can be compensated by the improvement of another. Yet this compensatory property—characteristic of any additive Value Function—only applies, strictly speaking, when attributes are mutually preferentially independent, as demonstrated by [56] and [15]. More in general, it is necessary to search for the appropriate aggregation structure to assure the internal coherence of the index. Multicriteria Analysis offers methods and tools that allow any index to be set up in a (theoretically) solid and (practically) satisfactory fashion; see, for instance, the multiplicative structures developed by [56] and by [62] or the heuristic and flexible additive–multiplicative structure proposed by [25].

In synthesis, the index structure should not be of the OOAO type, although it may not be additive, as a too low value of one only attribute may draw down the overall value. There are other structures which are more suitable and hence superior.

3. Proposal for an Adaptive, Pragmatic Approach to Planning

We have pointed out that in an increasing number of instances we are, and will be, obliged to envisage a socially desirable river configuration. We stressed that this is a multi-objective decision problem where the ecosystem value itself is one of the fundamental objectives (symbolized as N) amongst those identified. We pointed out, on the other hand, that all components of ecosystem health are worth considering, not just the biotic one ("Júcar problem"). We also noticed that the value we assign to an ecosystem depends both on its health (or ecological integrity), i.e., "how well it is" (Figure 4), and on its naturalistic relevance (or peculiarity), i.e., "how special it is". We argued that, in principle, what interests us is the whole trajectory of the state vector (a realization of a stochastic process): although it is essentially a "river somatism", it also captures the processes. As the aggregation of a (multi-dimensional) state trajectory is a difficult matter, referring to its final status only may be a sensible—albeit delicate—possibility. We argued that the common practice of including causal factors amongst the assessment attributes is incorrect ("dentist syndrome"). We focused then on the common (e.g., WFD) practice of adopting Reference Conditions (RC) as a pivot to assess the health of ecosystems and explained how, on the one hand, that is not solid ground, rigorously speaking, yet that, on the other, there is no better choice. Practically speaking, as discussed later, there are sensible operational criteria to define such Reference Conditions, an exercise that implies foreseeing the future climate. In parallel, we argued that the Leitbild alternative, promoted by several authors as the only meaningful solution (in particular by [33]), is not acceptable on ethical grounds, as well as because, conceptually, it cannot be set a priori, as it must be the result of a trade-off amongst the objectives involved (amongst these, the "N" that must hence be assessed independently); furthermore, because, by accepting the Leitbild approach, we increase the artificiality and fragility of the system, both undesirable outcomes. Further, we discussed the evaluation indices, how (even today) they generally disregard "internal coherence", one of the necessary basic properties, and hence in particular how the OOAO of the WFD structure should be modified, as well as the Italian IQM (which is affected by a number of additional weaknesses). On this basis, we conclude that, operationally, it is more advisable to assess the ecosystem value on the basis of a set of indices: one for its value (with two sub-indices: health and peculiarity); one for its artificiality, to keep track of the anthropogenic changes inflicted; and one for the threats that can possibly cause future dramatic and sudden changes (For instance: a break through a bedrock layer and consequent sink into a softer layer down to … who knows? Or a deficit of solid supply because of upstream reservoirs, which may become manifest in the near future as it generates a "wave of sediment deficit" travelling across the river. A fire de-stabilizing a valley slope that, vice versa, may supply more sediments; or the consequence of the introduction of a new species that may affect the stability of the levees).

The whole reasoning developed in this paper and our proposal are summarized in Figure 10 below. This commentary starts from Block n.2 (related to Nature objective N), moving to the right (the items that feed it), next converging in the central Block 1 further expanded, eventually ending up with conclusive considerations in the peripherical blocks.

3.1. Objective Nature (Block 2 and Related)

Blocks 2 to 8 focus on the search for a conceptually sound way to define and measure the N objective. In practice, this is a matter of building some key indices (the main one being the health index) in agreement with the WFD, yet also bearing in mind the suggestions we gave with regards to its logical and mathematical structure. Possibly the most critical point is the definition of the Reference Conditions (RC) as we are aware that this is not exempt from contradictions (e.g., no large fire would have occurred if the land use had not been modified). Conceptually, we propose a definition of the RC as the status that would exist today, provided no significant anthropogenic alterations had occurred within the basin, under current climate. Current climate has certainly been impacted by anthropogenic activity: on the one hand, this is a global scale process and hence it can be considered an exogenous input in each specific basin; on the other hand, climate evolves anyway so the assumption that the current climate (altered anthropologically) is 'the climate', allows findings more consistent with reality (imagine an ideal 'untouched' basin: it would display the RC as defined).

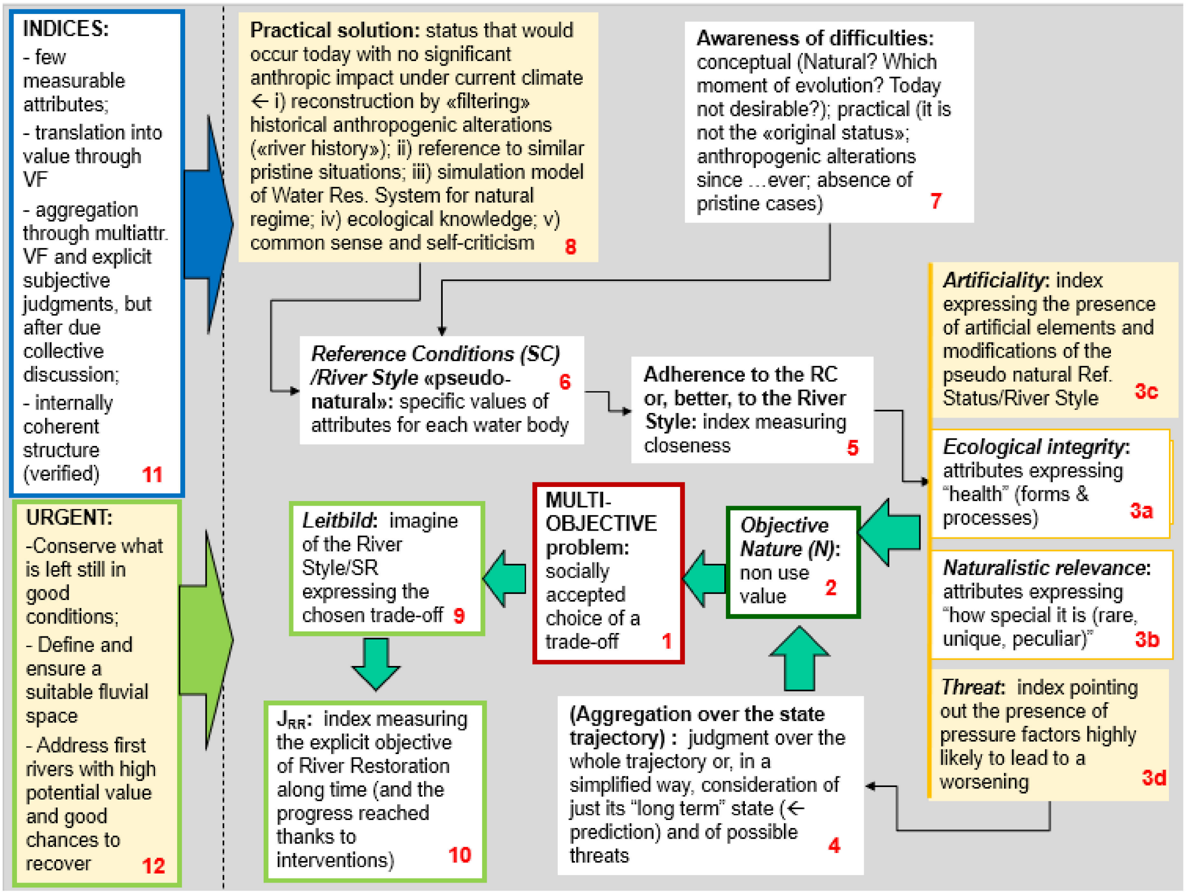

Figure 10. The reasoning and conclusions proposed in this paper are summarized in this figure: follow the numbering from the center towards the peripheral areas (the arrows mean "leads to", "is cause of", "is needed for"). The peripheral blocks on the left are intended to permeate the whole process.

Operationally, it is not easy to define the RC for a concrete case and the results may be affected by uncertainties and subjectivity; sometimes, even via a DELPHI process [63] it may not be possible to find a consensus. Nevertheless, there are useful guiding criteria that can be used to this end (of course, with the help of a good dose of common sense, self-criticism and flexibility):

- *Similitude:* in several cases, perhaps only for some components, it is possible to assume a similitude with (rare) pristine reaches of similar typology in a qualitative or even quantitative fashion (through statistical models, for instance as done for fish population in [64]). Hindcasting approaches such as those of [65] or [66] that look for a statistical link (regression) between riverine ecosystem attributes against a group of fixed factors (natural characteristics) and factors ("stressors") affected anthropogenically, like land use, seem an attractive option; the idea is that one does not know what was the pristine state, but at least can infer what (improved) biological status would occur once stressors were to be neutralized. This approach, however, as pointed out by its authors, must be used only within the boundaries of the empirical database adopted. It cannot be used to extrapolate a status not observed. Furthermore, it cannot be used in our case because we are defining Reference Conditions in a way that no empirical value of the regressors actually displays in the current world. Moreover, present conditions may have been affected by some "ecological catastrophe", for instance a widespread invasion by alien species, so that some native species may have already completely disappeared (but witnessed by historical documents) and cannot show up in the regression database. Finally, the human factors affecting the ecological status are very many and it is more than probable that the regression exercise may fail to capture some key issues. Because of one or more of these reasons, the hindcasting approach, if used for estimating the RC, might hence lead to a biased result. Nevertheless, when the DB is very wide (e.g., for lakes, [67]) and results robust, this technique offers a valuable possibility.

- *River history*: in order to speculate how the river "would be today", it is very useful to "filter" historical anthropogenic alterations. With this aim, it is key to understand how the situation has evolved starting from a status pre-dating significant anthropogenic impacts. This may be easily achieved for instance in Australia or New Zealand, but also elsewhere, e.g., in millenary China (see the extremely interesting paper by [68]) and in a country like Italy, even if so much impacted by a never ending succession of waves of civilization and barbarism. It is sufficient to remind ourselves of the deep transformations occurring since the mid-1800s—resulting from the important changes in land use due to industrialization—and then in the mid-1900s, following the construction of dams and defense works in the territory (levees, riprap embankments), as well as the practice of sediment mining for use as construction material (e.g., [69]). A very important first step is hence to reconstruct the "river history" through a schematic that shows the sequence of events related to all relevant causal factors (floods, dam construction, sediment mining, earthquakes, fires,) with the corresponding time evolution of the river state. On this basis, it is then possible to work out an "interpretative theory" that captures and highlights the key causal factors and processes (an example was proposed in [30]). This exercise takes advantage of aerial photographs (more recently, satellite and UAV images), as well as maps, reports of old travelers, historical pictures, archeological findings, geomorphic and vegetation evidence (dendrochronology; see, for instance, [70]), etc. It can be observed that a similar effort is always implicitly required by methodologies like the IDRAIM-IQM of [32,51];
- *Scientific knowledge*: basic knowledge of fluvial geomorphology, hydrology, hydraulics and ecology and current modelling capabilities, particularly for reconstructing the water regime, can be used at least in a qualitative fashion. A simulation model representing the current situation "with uses and works" and "altered land use", if well calibrated and validated, can be a means to reconstruct the natural regime, particularly if fed with a reconstructed land use and climate, once all works and uses are removed from the scheme.

In addition, we argue that the proposed approach would allow us to overcome the significant operational problems brought about by the "Heavily Modified Waterbody" concept. The WFD defines "Heavily Modified Waterbodies" (HMWB) as those water bodies evidently strongly altered because of anthropogenic pressures for which restoration would imply either an "excessive" cost and/or "too heavy impacts" on uses. For these, the WFD suggests the adoption of a "Maximum Ecological Potential" (MEP), rather than the RC, and pushes to strive to reach at least a status slightly worse than that, i.e., a "Good Ecological Potential" (GEP). This is evidently a vague and fuzzy concept, as demonstrated indirectly, for instance, by a EU review [71] that shows how each country defined GEP (or even did not define it) in remarkably different ways.

We argue that GEP generates an ill-posed problem similar to that related to the use of Leitbild, because MEP is the "highest Ecological Status reachable through interventions not significantly affecting uses and not implying disproportionate costs" (this is not a citation, rather a rewording from the WFD, easily verifiable from its Annex V, Sect.1.2.5); that is, it is an implicit trade-off amongst key objectives while, consistently with the multi objective approach, at this stage we must be concerned with N objective only. We claim moreover that this concept is simply unnecessary for rivers, as our scheme applies well enough. Firstly, it can be noted that the definition of RC for HMWB is possible and even easier than usual, as the distance from any "natural" state is so large that a partial and approximate definition of that "natural" state can work well. The N index will of course get very low values, but actions leading to (marginal) improvements are indeed possible (e.g., wastewater treatments; restitution of some space back to the river; introduction of fish ladders, as nicely summarized, for instance, in the cited EU report). Rather than undertaking a heavy (and costly) endeavor to define a fuzzy entity like "Ecological Potential", we suggest a minimum improvement to be achieved everywhere in terms of "sufficient" water flow; "sufficient" water quality (including thermal, radioactive, toxic, microplastics attributes), "sufficient" continuity for fish fauna and sediment transport; hydropeaking variations "sufficiently" limited; and "sufficient" presence of non-allochthonous fish (and absence of allochthonous) and riparian vegetation, at least in significant length reaches (i.e., 10–20 times reach width; i.e., there may be shorter reaches, particularly unhappy, with no fish, but on a significant reach there must be), all the rest being of course welcome. In all this, "sufficient" is defined as usual on the basis of the overall index for N, provided an improved evaluation index, sensitive to each single component, be adopted, as discussed previously. This position evidently means setting a minimum constraint to one of the involved objectives: N.

3.2. Fundamental Objectives (Block 1)

The ability to assess the level of achievement of the N objective is just one of the required elements needed to undertake the overall planning framework. To this aim, we must now specify the fundamental objectives, i.e., what feeds Block 1 of Figure 10. Here is our proposal based on experience and logic:

(N) *Natural value of the river* (to be maximized): This is the nominal main objective of River Restoration actions and is at the center of the discussion developed in the previous paragraphs.

(R) *Hydro-morphological Risk* (to be minimized): a combination of *hazard* from flooding and geomorphic fluvial dynamics (normal or residual associated with events superior to the design event or with the potential work collapse), of *exposed value* (current and future, the latter being usually higher when the realization of protection works creates a psychological climate of "safety") and *vulnerability* (possibly reduced by preventive interventions or real time management strategies).

(D) *Social Disturbance* (to be minimized): this includes all what disrupts, perturbs or merely annoys existing social settings, such as:

- loss of land value because of land-use changes (e.g., new constraints, de-classification of zones)
- reduction of water availability owing to different uses (typically to fulfil more demanding ecological requirements of the hydrological regime)
- relocation of particularly exposed (or interfering) buildings and infrastructures
- imposition of payment schemes for environmental services on some social groups (e.g., upstream stakeholders are compensated when they allow the river to flood/wander on their properties so as to reduce downstream damages).

(S) *Environmental Services* (to be maximized or, at least, kept at current level): among these Water supply, Hydroelectric production, Effluent disposal, Support to navigation, Availability of space for anthropogenic activities (agriculture, urban settlements, other infrastructures), Recreation, Aesthetic appreciation, Cultural legacy or identity.

(C) *Total Costs* (to be minimized): investment plus Operation, Management, periodic Replacement (OMR) and Dismantling.

(E) *Negative Externalities* (to be minimized): for example, flood peak increment downstream, pollutants load exported from a sub-basin, excess/deficit of solid load conveyed in a reach (which might rebound, even upstream, because of regressive erosion).

3.2.1. Other Objectives and Criteria

Each project/plan/policy may enunciate particular objectives that do not fit into the above categories, e.g., "reducing water turbidity" is a fairly common example. However, such objectives are mostly "components" of the fundamental ones (e.g., less turbidity implies a recreational advantage or, in case of drinking water use, lower water treatment costs, thus better environmental services). They may also represent "causal factors" that, in a cause–effect conceptual network, contribute to arriving closer to (or farther from) the fundamental objectives. For instance, increasing knowledge and awareness about a river status may lead, in the medium or long term, to actually improve that status. Each project needs to focus on the achievement of its own stated objectives; nevertheless, it is essential to show explicitly the link with the fundamental objectives, because the non-fundamental alone do not allow judgement as to whether that project deserves the required effort (in terms of money, time, etc.) or not.

When evaluating projects/plans/policies, several criteria other than those so far here indicated can be adopted. For instance, consistency with hierarchical planning; feasibility; consensus; replicability, stimulation power; etc. These criteria are quite useful to rank alternatives; however, they do not allow judgement as to whether a project deserves or not to be implemented because they do not fall into any of the fundamental categories with which a clear value is associated. They can hence be adopted only when a defined plan is provided, so it is a matter of prioritizing actions within it.

3.2.2. Measuring the Objectives: Indices and Prediction Tools

All the stated objectives, as already discussed, can be measured on the basis of suitable indices, particularly if the Value Function technique is adopted as it increases the chances that 'internal coherence' is fulfilled, which is a key requirement. Subjectivity cannot be eliminated; it rather has to be properly managed through participatory techniques be it within the experts' domain (DEPLHI techniques), or within the public domain (mainly through dialogue) (Block 11, Figure 10). In order to measure an objective, it is of course necessary to predict the value of the involved attributes according to the consequences of the set of decisions assumed in a given plan/project alternative. This implies the use of suitable cause–effect models ranging from empirically based statistical models to physically based or conceptual mathematical (or even material) models or even expert-based models, most frequently a mix of these, to take due account of the key role of biotic components, according to the "biomic restoration approach" [21].

3.3. A Key Decision: The Fluvial Space

While pursuing the stated objectives, a number of choices with regard to decision variables must be made. One such key decision concerns the space assigned to the river (*fluvial space*) as this influences its ecosystem status (the HyMo component) as well as several other key objectives, such as hydro-morphological risk reduction and anthropogenic activities (e.g., recreation and aesthetics). In addition, space availability is key to ensure a sufficient degree of resiliency in any restoration project [72]. Without a clear decision on the space issue, very little structural restoration or enhancement is possible, nor is possible adaptation to future climate. Besides, once the fluvial space is lost, it is very rarely recovered, while exposed value undoubtedly increases. In this sense, preserving a significant free space is possibly the most rewarding investment.

3.3.1. The Fluvial Space Output of a Multi-Objective Problem

It is useful to distinguish the Desired Fluvial Space from the Natural Space (i.e., the space that the river would have if undisturbed) as well as from the Current Space (the space it actually has at present) and the Administrative Space (the space assigned by laws and planning) [73]. Land use changes, Climate Change (CC) and evolving preferences (e.g. the increasing demand for a healthy environment) ensure that the Desired Fluvial Space cannot coincide any longer (if ever) with Current Space. Taking CC in particular, it must be recognized that fluvial systems are becoming far too costly, as defenses increase and require additional and eternal Operation-Management-Replacement expenditures, as well as fragile, as residual risk (damages occurring because of events higher than those designed and/or the collapse of works) is dramatically increasing. All this requires more space (the most essential Nature Based Solution) and fewer works.

The choice of a Desired Fluvial Space with its associated morphological configuration and system of hydraulic and defence works/interfering infrastructures, both at the local scale and at the hydrological network scale [74], should be the fruit of an informed societal choice, through a participatory process. The multi-objective approach offers a natural support for a negotiated solution as shown schematically in Figure 11 (see for instance [7,75–79]).

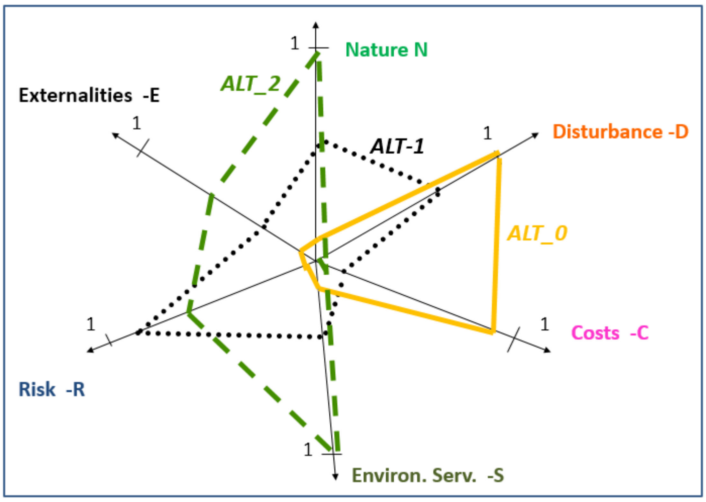

Figure 11. In the hypothetical example, the ALT_0 alternative ("business as usual") induces the least disturbance because it does not touch the "status quo" and implies the least cost, as it does not require investments; yet it behaves very badly from all other points of view. ALT_2 performs best over the N objective as well as over the other environmental services (S), but is the worst in terms of costs. (The "radar" representation adopted here is just one amongst others, e.g., histogram, tables, etc., and is not always the best; it requires a normalization of the objective and a positive orientation of the axis, i.e., "1" is the best, while "0" the worst. What counts is the position on the axis, not the undercut areas).

3.3.2. Leitbild after the Multi-Objective Choice

It is at this stage that the Leitbild comes in handy (Block 9, Figure 10): it provides a shape to the chosen trade-off amongst the fundamental objectives, including the "Nature" objective N. The Leitbild defines a desired River Style which is feasible within a context partly anthropized in terms of infrastructures and land use. For instance, a dam might be deemed necessary; hence a new river is accepted downstream for which a specific Leitbild is defined, typically characterized by dynamic geomorphic equilibrium and features different from the pre-dam features: for instance, a meandering river (reducing slope and hence solid transport capacity to compensate for the trapping effect of the reservoir), with processes and habitats suitable to maintain the desired species that may even be allochthonous (along the lines of the emblematic Colorado case earlier cited). This approach is indeed similar to the one proposed by [80], a two stage process (first, they assess the deviation with respect to a natural condition called "visionary Leitbild" and then they set the objective of restoration with a "practical Leitbild"), with the difference, however, that their "visionary Leitbild" was identified as the historical status, which we have discarded in our previous argument.

It is hence on this Leitbild, adopted as a reference, that a meaningful success index can be built, i.e., an additional evaluation index that allows the assessment in an objective and transparent manner of the degree of success of a restoration/rehabilitation policy/plan/project by measuring how close to the Leitbild we are effectively arriving at (Block 10, Figure 10).

3.4. Adaptive Approach

Our knowledge of the natural world is still very limited: there are uncertain and unpredictable factors that can significantly modify the evolution of a river as well as changes in the needs and desires of society. Therefore, an adaptive approach is inevitably required to deal with such a complex problem. Accordingly, decisions must be progressively adjusted as soon as new elements arise and in harmony with what the behaviour of the managed river reveals [81]. Being "adaptive" means, in addition, preferring "flexible decisions", i.e., decisions that are compatible with possible future changes in case scenario variables will prove to be worse or . . . better than foreseen now [82]. In such a way, on the one hand, the whole cost of facing the harshest scenario is diluted in time and hence there will be no regret at an excessive expenditure in case the situation proves smoother; on the other hand, it will be possible to take more serious actions on the basis of those already taken with no economic losses (e.g., a levee can be further elevated if the basis is sufficiently robust), in case worse scenarios emerge.

We are aware that there is a whole research corpus on the analysis of the foundations and characteristics of decision making approaches pointing out the need for a transition to adaptive approaches (e.g., [83,84]), or even analyzing their historical evolution showing how these approaches have been moving towards the incorporation of "adaptive" ability (e.g., [85]). Here, we want to focus on what "being adaptive" may imply when dealing with the fluvial space issue, without even trying to introduce a new definition and appropriate label for what we are suggesting.

Being "adaptive", however, does not mean we have to give up on selecting and specifying a certain River Style we wish to aim for and on choosing a corresponding trade-off amongst the different conflicting objectives. Otherwise, we would proceed blindly. Planning is also required to fulfil a societal pact with citizens. However, it must be accompanied by the awareness that these choices may be modified later on, hopefully in a non-dramatic fashion, explicitly, yet not too frequently (otherwise planning would be useless). Figure 12 illustrates this idea.

3.5. Other Key Pragmatic Inputs for Decision Making

All this conceptual architecture concerning the definition and measurement of objectives and choices must not distract us from our purpose to improve decision-making processes, thus leading to a veritable (imperative) improvement of ecosystems: we need a strong strategy in order to save what is still in good condition and to improve what has already been altered (through restoration or rehabilitation). Pragmatically, current trends depict an incoming future where the most sensible strategy is simply (Block 12, Figure 10):

- the identification and strict protection of preservation & conservation zones on the basis of their current high environmental value (health and peculiarity), including the zones from which their configuration depends upon (e.g., their mountain catchments). This is in general only possible through delicate participatory, extensive work with local communities and the establishment of working management schemes such as the Payment for Environmental Services or "Water Funds" (e.g., [86]);
- the application of the evaluation criteria and methods discussed here to those rivers/basins consciously targeted for exploitation or for the development of impacting projects
- the adoption of the best design/implementation practices offered by the River Restoration corpus (see www.ecrr.org, accessed on 6 May 2021, for instance), including newer techniques for water management like the wide-ranging family of Nature Based Solutions applied to drainage and treatment;
- in the altered zones, the prioritization of ecosystem elements at different scales (river stretches, corridors, hydraulic annexes, basins) to be recovered, enhanced or restored. High on the list are those elements with a significant potential ecological value (today possibly remarkably diminished) and with a good recovery capacity, but also, conversely, those elements whose degradation has reached unacceptable levels (e.g., highly polluted sites).

This actually resembles the strategy adopted by the European Commission through a number of EU Directives, although not as compact and synthetic.

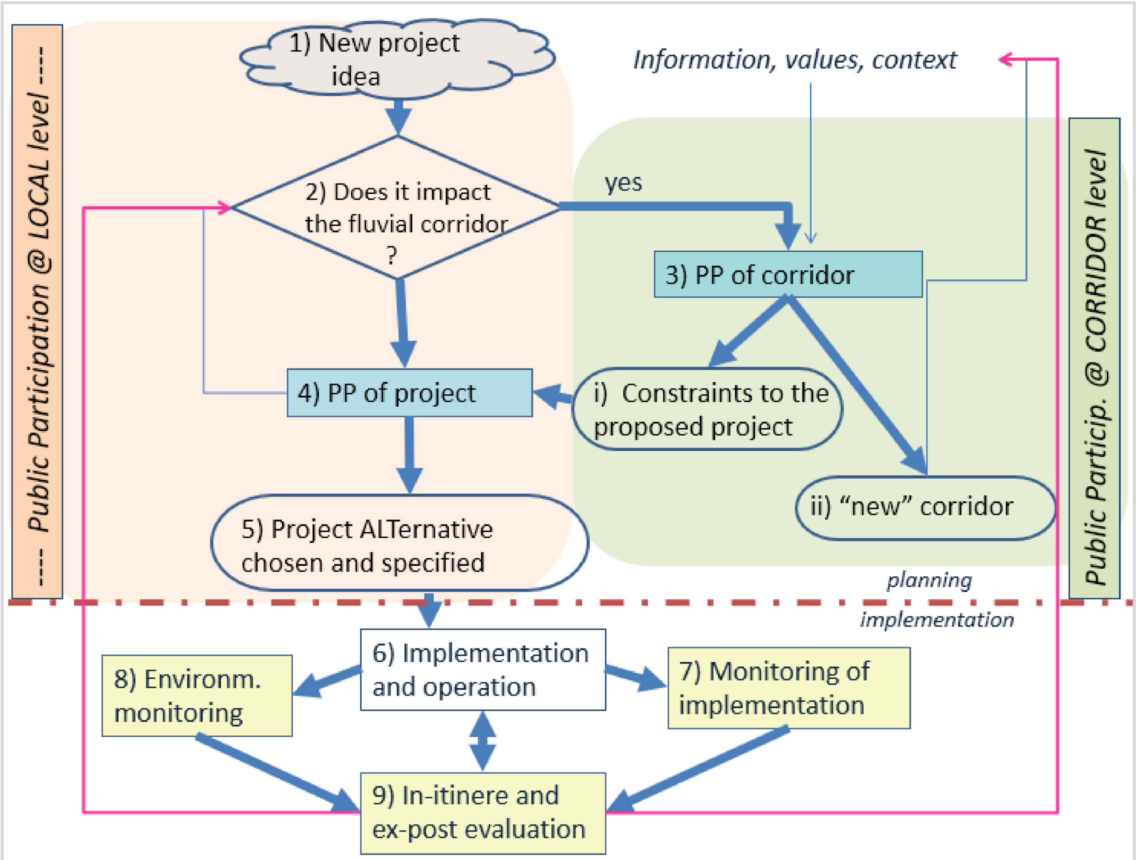

Figure 12. Algorithm for adaptive Participatory Planning Process (PP) for the definition and adaptive management of a fluvial corridor (the fluvial space) at the planning level (above) and at the implementation level (below). We assume that the fluvial space has been set, so defining a river "corridor" (stressing that this includes not only the active channels themselves, but also a portion of the floodplain with its geomorphological units and its system of exploitation and control works). At a certain point in time, a new project may come into play which aims at river restoration (e.g., re-meandering), or at river exploitation (e.g., a hydropower plant), or management (e.g., sediment re-distribution), or simply for any other purpose that may have some impact on the river (e.g., a road). The scheme envisages a PP at the "local" scale (i.e., of the Project itself), and at the "corridor" scale, depending on the impact level of the proposed new project. A decision is first issued on which level to address, based on an extended Environmental Impact Assessment that includes all relevant objectives, including economics. At the local level, the PP will not change the fluvial space, but may change the project (e.g., through suitable mitigation or compensation measures or even rejection); at the corridor level, the PP might end with a modification of the fluvial space previously established and, typically, with constraints to be fulfilled by the project. Environmental and implementation monitoring are essential components both during planning and implementation ("in itinere") and afterwards ("ex post").

4. Conclusions

Our world more and more resembles a piece of gruyere cheese: very few zones will be kept almost natural (at high cost) while all the others will be deeply artificialized. This discourse is particularly relevant and important for developing or emerging countries, where the rate and magnitude of negative environmental change is unprecedented. Hopefully, at least, this artificialization may be properly managed.

In this paper, we critically examined diverse aspects that influence today's conception and practice of river management and restoration. Our argumentation started from the consideration that, one way or another, rivers are modified by human activity. In the best of cases, this may occur on the basis of a structured, participatory planning process and informed management. We pointed out that this kind of process practically always involves multiple conflicting objectives; hence, in order to reach a serious improvement in decision-making, we need to upgrade our ability to conceive, define and use objectives. We then focused on how we can structure conceptually the N objective and how all objectives can be measured (the indices issue). We noticed that one of the key decision variables is the fluvial space and that the multi-objective framework is suited to support this choice. We then outlined a specific and conceptually clearly defined role for the Leitbild approach and we proposed a simple, overall, pragmatic strategy, in order to avoid missing the priority of concrete action.

We believe that this may provide a useful integrated and harmonized view that eventually will support society to better decide what kind of river is "the river we wish for".

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