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A CONTRIBUTION TO IDENTIFY THE "REFERENCE CONDITION" FOR APPLYING RIVER QUALITY INDEXES IN MEDITERRANEAN TORRENTS

Giuseppe Bombino[1*], Bruno Gianmarco Carrà[1], Daniela D'Agostino[1], Pietro Denisi[1], Antonino Labate[1], Antonella Nucera[1], Demetrio Antonio Zema[1], Santo Marcello Zimbone[1]

(1) Department "AGRARIA" – Mediterranea University of Reggio Calabria - Loc. Feo di Vito - I-89122 Reggio Calabria (Italy)

**email: giuseppe.bombino@unirc.it*

KEY POINTS

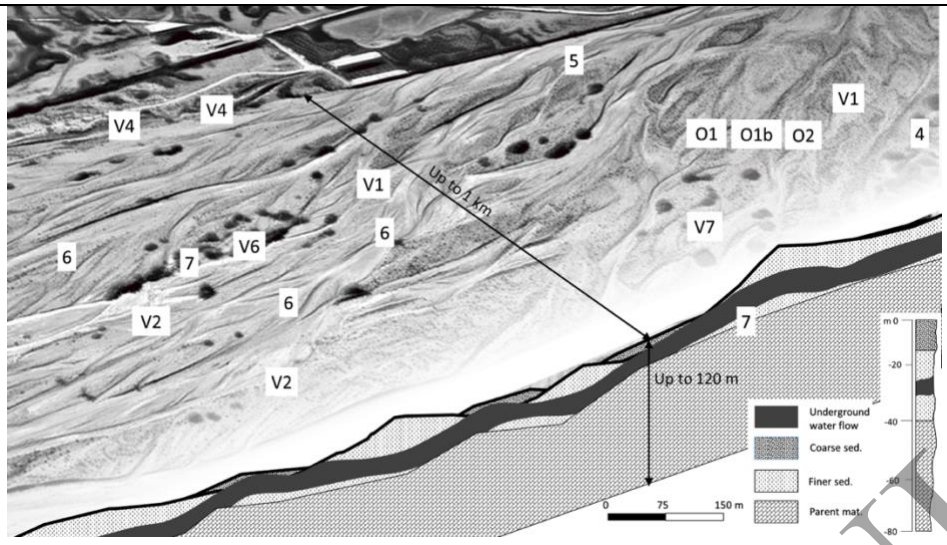
- The MTs characteristics were described for defining the river reference conditions
- The peculiarities of the MTs could be used to define the reference condition for a generic MT.
- Three river quality indexes have been tested in a Mediterranean Torrent (MT)
- The MQI index is able to evaluate MT quality but does not consider the reference condition
- Synthetic indicators, could improve evaluation of river morphology and ecology of MTs.

1 INTRODUCTION

Riparian ecosystem quality (WFD; European Commission, 2000) depends on the equilibrium between geomorphological, ecological and hydrological elements that, in absence of anthropic disturbance, expresses the naturalness level of a river (Gonzales del Tanago et al., 2006). In order to evaluate the riparian ecosystem quality WFD has defined the concept of river "reference condition" (Nijboer et al. 2004) and several indexes have been developed for evaluating the river status with respect to its "optimum". However, in the case of the Mediterranean Torrents (MTs), the interactions among geological, morphological, hydrological and climatic components and their effects on river ecology and riparian habitats are poorly studied, making the application of river quality indexes a difficult task. Moreover the changing environment of MTs context, along with the natural "disorder" of these peculiar rivers, increases the difficulties for interpreting and defining the reference condition of MTs. Consequently, studies are needed to support the ease evaluation of the river quality (Fernandez et al., 2011; Ollero et al., 2011). At this aim, this study proposes: i) a characterization of the reference conditions for MTs and ii) a comparison of three river quality indexes, to improve their efficiency towards a realistic interpretation of the peculiar characteristics of these torrents.

2 MT REFERENCE CONDITION

The typical torrents of Southern Europe show intrinsic hydrological, geomorphological and ecological characteristics, in response to the Mediterranean climate. Many studies (e.g., Sabato et al., 2004, Bombino et al., 2006, 2011 and Zema et al., 2018) have described the high temporal and spatial variability of the characteristics of the MTs, identified as the main causes of their "non-equilibrium" state. This very changeable condition makes MTs very peculiar contexts; the natural "disorder" of them is difficult to interpret, making hard both the evaluation and the identification of the continuous changes taking place in the MTs. In order to define the "reference condition" for MTs, Bombino et al. (2006 and 2011) have evaluated the effects of control works (check dams, embankments, etc.) on the ecology and hydrogeomorphology; the same authors also have developed synthetic indicators to evaluate the riparian vegetation (in terms of evolution, structure global canopy cover, naturalness, biodiversity and species richness) and geomorphological characteristics (channel geometry, sediment size, connectivity, etc.) of the regulated reaches in comparison to undisturbed channels (considered as reference). These studies have allowed depicting environmental actions and the related ecological effects on vegetation and other biotic components of MTs. A schematic description of the "reference condition" for MTs, integrating the previous studies, is proposed in the Figure 1.



	Environmental actions	Ecological effects	
		On vegetation	**On other biotic components**
CLIMATE	[**1**] Prolonged drought periods in the river bed	Vegetation composed of pioneer plants established for a short period (one season) [**V1**]	Macrobenthic communities, fish fauna and retention structures of trophic matter limited in quantity and distribution [**O1a**] Organic matter located along the riverbanks only and poorly decomposed [**O1b**]
HYDROLOGY	[**2**] High occasional and variable discharge/sediment transport, and seasonal flow regime	Vegetation frequently removed by intense flow [**V2**]	Well diversified but unstable (in terms of space and time) trophic retention structures [**O2**]
	[**3**] Destructive flood events that occurring during heavy rainfalls	[**V1**], [**V2**]	[**O1**] + Retention of trophic matter in small quantities and located along the riverbanks [**O3**]
GEO-MORPHOLGY	[**4**] Presence of small areas inundated by high return time floods	Riparian vegetation replaced by terrestrial communities [**V4**]	**[O1b]**
	[**5**] Widespread erosion processes along the river bed caused by floods	Vegetational dynamics are interrupted or annihilated [**V5**]	[**O2**]
	[**6**] Slightly accentuated slopes and wide cross-sections with multiple braided thalwegs	Poor-developed vegetation following the presence of the stream-flow in the river bed [**V6**]	[**O1**]
	[**7**] Very deep and permeable alluvial debris and stream flow draining underground (hypodermic runoff)	Highly fragmented plant communities [**V7**]	[**O1**]

Figure 1 – The basic interaction between hydrology geomorphology and vegetation in undisturbed valley reaches of MTs (letters and number are explained in the related table).

3 MATERIALS AND METHODS

3.1 Study area

The investigation has been carried out in the middle-valley reaches of the Amendolea torrent (Ionian coast of Southern Calabria – Figure 2). The selected MT shows a high degree of naturalness; as a consequence, its ecological and hydro-geomorphological dynamics attain the maximum evolution level.

Figure 2 – Location and map of the studied catchment with the 15 sub-reaches

3.2 Application of three river quality indexes and evaluation of their performance

Reference conditions for MTs have been evaluated by applying three river quality indexes. Among the several river quality indexes of literature, we have considered the most suitable for the semi-arid conditions: i) the Index of Fluvial Functionality (FFI, Siligardi et al., 2007); ii) the hydro-geomorphological index (IHG, Ollero et al 2011); and iii) the quality morphological index (MQI , Rinaldi et al., 2012). The FFI considers all the biotic elements of the river ecosystem; the IHG is based on the assumption that all the impacts caused by human activities on the river system have hydrological and geomorphological effects on the morphology of the riverbed and river banks and the MQI is designed to comply with WFD requirements and considers fluvial processes rather than channel forms only.

The three indexes have been applied and evaluated as follows:

- Identification of MT sub-reaches. Through field surveys, and ecological and environmental analyses, the Amendolea torrent has been divided in 15 sub-reaches with homogenous climatic, hydrogeomorphological and vegetational characteristics (Bombino et al., 2006).
- Application of the indexes, according to the developers' methodologies.
- Evaluation of index performance. The "score" that each index attributes to the related "question" (attaining to a torrent characteristic) in the studied sub-reaches has been calculated and normalised, in comparison to the reference condition of MT. Then, a cross-evaluation procedure has been adopted for the index comparison.

4 RESULTS AND DISCUSSION

The scores given to each question of the three indexes were carefully attributed considering the reference condition of MT. Score class distribution and its frequency of the three indexes is reported in Table 1. It shows as the highest values for the three indexes have been recorded in the sub-reaches closer to the mouth. In the upper sub-reaches the II and III IFF functional levels are quite equally represented, while the IV category appears in the lower ones. Both MQI and IHG have the upper sub-reaches categorized as good-very good classes.

Index	Score class	Sub-reach	Index	Score class	Sub-reach	Index	Score class	Sub-reach
	II (201-250)	3		Scarce (21-41)	7		Poor (0,3-0,5)	2
	III 121-180	5		Moderate (42-59)	3		Moderate (0,51-0,7)	2
FFI	III-IV (101-120)	5	HGI	Good (60-74)	3	MQI	Good (0,71-0,85)	4
	IV (61-100)	2		Very good (75-90)	2		Very Good (0,86-1)	7

Table 1 - Score class distribution for MQI,IHG and FFI indexes in each studied sub-reach (Amendolea torrent, Italy).

The application of FFI in the MT has been difficult, since it does not properly evaluate the potential functionality expressed by the different biotic and abiotic components of the MTs. This critical issue has led to include many sub-reaches in the III and IV functional classes. IHG includes many sub-reaches in the lowest

quality class, because it only considers environmental and hydrogeological alterations. Conversely, the higher correlation was observed in MQI with the other two indexes. MQI is correlated to both FFI ($r^2 = 0.79$) and IHG ($r^2 = 0.69$), whereas the latter indexes are scarcely correlated each other ($r^2 = 0.45$). MQI reports almost all the questions of FFI and IHG, therefore it seems to be the most comprehensive of the evaluated indexes (Figure 3). As a matter of fact, MQI is able to describe both the biotic and abiotic components of the MTs, therefore many sub-reaches are classified as high quality sub-reaches. The reference conditions for MT are not completely defined within the index so that the MQI application will improve taking into account river references elements for these contexts. Differently by the other indexes, MQI, has a relatively high number of indicators allowing an overall and meaningful assessment of the morphological conditions in MT.

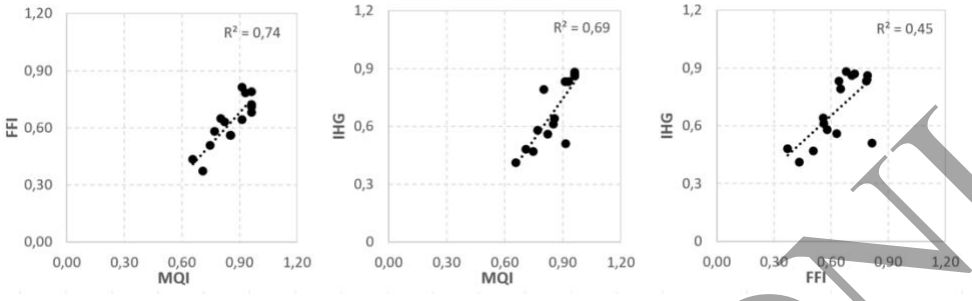


Figure 3. Linear regression between MQI, IHG and FFI applied in 15 sub-reaches of the Amendolea torrent (Italy).

5 FINAL REMARKS

MQI has proven to be the most suitable index to interpret the typical high ecological variability of MTs. However, this index is able to depict the MT naturalness, but does not take into account the ”optimum status” for comparing the river quality deviation. At this aim, the peculiarities of the MTs reported in this study could be used to define the criteria for specifying the reference condition for a generic MT. A set of synthetic indicators, previously developed and tested by the Authors (Bombino et al., 2003, 2006) could be integrated into the MQI for a more accurate evaluation of river morphology and ecology quality.

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