Environmental Impact Assessment Review 63 (2017) 136–146

Contents lists available at ScienceDirect

Environmental Impact Assessment Review

journal homepage: www.elsevier.com/locate/eiar

Assessing the impacts of water abstractions on river ecosystem services: an eco-hydraulic modelling approach

Mauro Carolli*, Davide Geneletti, Guido Zolezzi

Department of Civil, Environmental and Mechanical Engineering, University of Trento, Via Mesiano 77, Trento, Italy

ARTICLE INFO

Article history:
Received 25 July 2016
Received in revised form 22 December 2016
Accepted 22 December 2016
Available online 21 January 2017

Keywords:
Habitat modelling
Hydropeaking
Hydromoprhology
Water abstractions
Run-of-river hydropower

ABSTRACT

The provision of important river ecosystem services (ES) is dependent on the flow regime. This requires methods to assess the impacts on ES caused by interventions on rivers that affect flow regime, such as water abstractions. This study proposes a method to i) quantify the provision of a set of river ES, ii) simulate the effects of water abstraction alternatives that differ in location and abstracted flow, and iii) assess the impact of water abstraction alternatives on the selected ES. The method is based on river modelling science, and integrates spatially distributed hydrological, hydraulic and habitat models at different spatial and temporal scales. The method is applied to the hydropeaked upper Noce River (Northern Italy), which is regulated by hydropower operations. We selected locally relevant river ES: habitat suitability for the adult marble trout, white-water rafting suitability, hydroelectricity production from run-of-river (RoR) plants. Our results quantify the seasonality of river ES response variables and their intrinsic non-linearity, which explains why the same abstracted flow can produce different effects on trout habitat and rafting suitability depending on the morphology of the abstracted reach. An economic valuation of the examined river ES suggests that incomes from RoR hydropower plants are of comparable magnitude to touristic revenue losses related to the decrease in rafting suitability.

1. Introduction

Many river watersheds worldwide have been managed to maximize the provision of specific ecosystem services (ES), often by altering the river channel morphology and its hydrological regime. River ES are directly related to the physical and biological characteristics of the river channel, and depend on its hydro-morphological and ecological dynamics (Vermatt et al., 2013). These dynamics are fundamentally tied to the spatial and temporal variability of water availability, i.e. to the flow regime (Poff and Zimmerman, 2010). The effects of flow regime alterations on river ES are still under investigation. For instance, in spite of the importance of cultural ES provided by rivers (Russi et al., 2013), only few studies quantified their variations in relation with flow regime, and usually only by expert-judgement (Shelby et al., 1998). Fanaian et al. (2015) linked the economic value of selected ES (hydropower, irrigated agriculture, fishery, wildlife tourism and flood regulation) with the flow regime of the Zambesi River and built different management scenarios in order to evaluate the effects of flow regimes. Large and Gilvear (2014) proposed a spatially explicit approach to evaluate the capability of a river to sustain eight ES on the basis of 18 features, but the analysis largely focuses on geographical and morphological features. Among the most important causes of alterations of river natural flow regime are water abstractions, often associated with hydropower production (Poff and Zimmerman, 2010). Production schemes modify the flow regime on a seasonal and daily scale (Zhang et al., 2010), as well as on a sub-daily scale by the discontinuous releases from hydropower plants, producing the so-called "hydropeaking" phenomenon (e.g., Carolli et al., 2015). Considerable improvements have been made within the interdisciplinary scientific community of river scientists to quantify and predict the response of river hydromorphology and ecology to flow regime regulation (e.g., Bruno et al., 2013; Poff and Zimmerman, 2010; Vanzo et al., 2016). However, such advances have not been fully exploited so far to develop quantitative predictive tools to assess the impact of flow regime alterations on river ES. The inclusion of ES in the impact assessment of projects, plans and policies has been increasingly addressed by the scientific literature over the last few years. Experiences and viewpoints on this topic have been collected by Geneletti (2013), and practice reviewed by Rosa and Sánchez (2015). Methods have been advanced to include

* Corresponding author.
E-mail addresses: mauro.carolli@unitn.it (M. Carolli), davide.geneletti@unitn.it (D. Geneletti), guido.zolezzi@unitn.it (G. Zolezzi).

http://dx.doi.org/10.1016/j.eiar.2016.12.005
0195-9255/

ES in impact assessment for higher level policies (Helming et al., 2013), plans (Geneletti, 2015, 2016) and projects (Mandle and Tallis, 2016). All these studies show the emerging interest in this area, but also the need for applications across a broad range of sectors. The aim of this work is to propose a method to i) quantify the potential of rivers to provide ES under flow conditions modified by large hydropower production, ii) quantify the impacts of water abstractions in different sites under increasing abstracted flow rates, and iii) predict how different ES respond to water abstraction alternatives. The method is applied to the upper course of the Noce River in the Trentino region, Northern Italy.

2. Study area: the Noce River

The Noce River is one of the main tributaries of the Adige River, located in the North-Eastern Italian Alps (Fig. 1). Since the 1920, the Noce River and its catchment have been subjected to human alterations implying the reduction of the river channel area, embankments and construction of dams for hydropower production. Two large dams are close to its sources and fed a hydropower plant which released water cause sub-daily artificial flow oscillations (*hydropeaking*). We selected three main ES: river recreation, in terms of white-water rafting, provision of habitat for the adult marble trout (*Salmo marmoratus*) and hydroelectricity production from RoR plants. See also La Jeunesse et al. (2016) for a detailed description of water uses in the Noce River basin. Rafting and canoeing activities have become popular in the Noce River area and they are an important source of income for the local population during the summer season. The Noce River has been ranked among the top ten streams for white-water rafting worldwide (National Geographic Travel, 2014). The most relevant fish species of the Noce River is the marble trout, endemic of the Southern Alps and classified as endangered in the EU Habitats Directive. The evaluation of fish habitat is fundamental in present and future management of water abstractions options because fish population can be greatly affected by the habitat quality (Eklöv et al., 1999). The large storage hydropower scheme is located upstream the study reach (Fig. 1) and it has been considered as a boundary condition of the model in this work. In addition, the Noce River catchment is experiencing an increase of demand of licenses for hydroelectricity production from RoR plants, which has been dramatically increasing in the whole Alpine area in the last years by private and public bodies (Platform Water Management in the Alps, 2010). This is determining a further alteration of the flow regime at sub-reach scale and unclear and understudied consequences on river systems and on its ES. The Noce River in the study area (in green in Fig. 1) has been partitioned into four reaches with homogeneous streamflow conditions, in consideration of the spatial streamflow variability due to lateral major and minor tributaries (sub-basins contributing to reaches 1, 2, 3 and 4 in Fig. 1). Two water abstraction sites, namely AS1 and AS2, associated with two hypothetical though realistic future hydroelectricity production from RoR plants are considered in the present study. We simulated an abstracted flow rate increasing from 1 to 7 m^3s^{-1} for each site, which are mutually independent. Their position, length, abstraction and release section are shown in Fig. 1.

3. General methodology

We selected ES indicators related to the flow regime and we calculated their variations by a modelling approach. The combination of hydrological simulations, hydraulic and ecological models, and preference functions allows to evaluate the provision of ES which depends on the channel morphology and on the flow regime. The hydro-morphodynamic models simulate the spatial distribution of desired hydraulic variables (e.g., water depth, flow velocity) and the results are combined with the flow regime patterns and its temporal variations, which are associated with natural events or different flow management strategies and are predicted by a hydrological model. On this basis, a suitability indicator for each ES is computed. Finally, the indicators are aggregated at the desired spatial and temporal scales by applying suitable averaging and weighting techniques. The river suitability for each ES is then compared. The methodological steps are the following:

1. Quantification of the ES provision (Section 4.1). Definition of the relation between ES and physical variables through the definition of preference functions.
2. Hydraulic and habitat modelling (Section 4.2). Hydraulic simulation of the spatial variability of the flow parameters, required by the habitat model and on which the preference functions depend. The habitat modelling combines preference functions and physical variables and allows to compute streamflow thresholds for ES suitability.

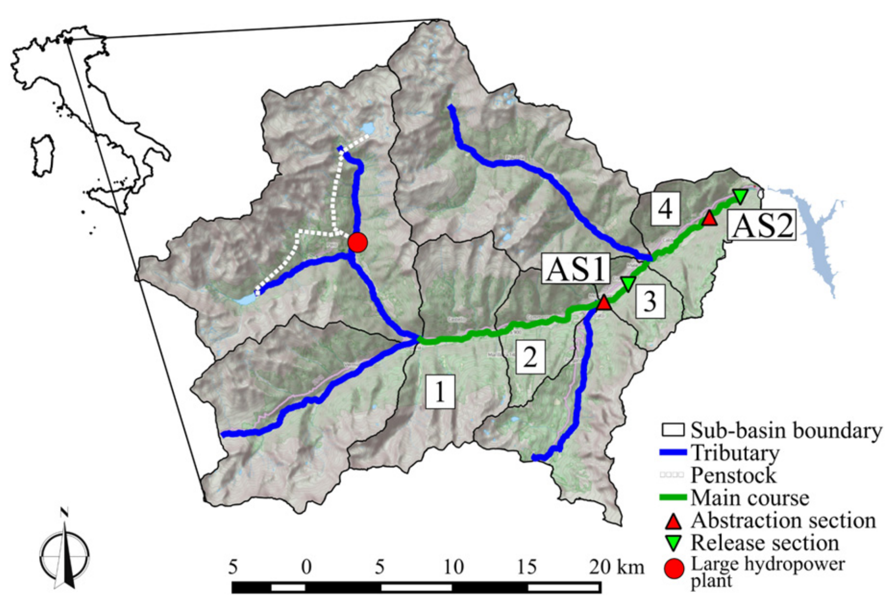

Fig. 1. Map of the upper Noce catchment. AS1 and AS2 are the water abstraction sites.