Estimating the (cultural) environmental-economic benefits/values of surface water status improvements in freshwater ecosystems: the *Pateira de Fermentelos* in Portugal

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ABSTRACT

Freshwater wetlands provide crucial ecosystem services that influence climate, nutrient cycles and primary productivity – hence contributing to social welfare and human well-being. These ecosystems are subject to anthropogenic and natural stressors, including from pollution, population growth, economic development, resource depletion and climate change. Anthropogenic stressors have, frequently, provoked devastating impacts on freshwater wetland ecosystems, resulting in a loss of ecosystem services and values. The EU Water Framework Directive (WFD; 2000/60/EC) aims to achieve good status of surface waters across EU member states by 2015, through implementation of Catchment Management Plans (CMPs). While implementation of CMPs is known to be costly for farmers, industries and citizens, associated benefits from improvements in surface water status are less well known. In particular, there is a lack of studies that consistently assess environmental-economic benefits/values of continuous changes in surface water status (i.e. chemical and ecological status). This paper establishes a functional relationship between surface water status and (cultural) environmental-economic benefits/values of freshwater systems. Hence we develop an environmental-economic valuation approach, in which we relate ecological status and chemical status of surface waters (based on local cross-section survey data) to willingness-to-pay (using benefit-function transfer techniques). Results for the *Pateira de Fermentelos* freshwater wetland (central Portugal) show that the current status of surface waters is good from a chemical perspective though only mediocre from an ecological perspective. The current (cultural) ecosystem service value of the *Pateira de Fermentelos* is estimated at 1.54 m€/yr – increasing to 2.02 m€/yr in case good status of surface waters is obtained.

KEY WORDS: *Surface water status; Freshwater ecosystem services; Willingness-to-pay; Benefit-function transfer*

INTRODUCTION

Freshwater wetlands, like the *Pateira de Fermentelos* in the Cértima catchment (Portugal), are extremely productive and provide crucial ecosystem services that influence climate, nutrient cycles and primary productivity on a global scale – hence contributing directly and indirectly to social welfare and human well-being (Costanza et al.,1997; Keddy et al., 2009). These as well as other ecosystems are subject to several anthropogenic and natural stressors, including from pollution, population growth, economic development, resource depletion and climate change (Teles et al.,2007; Reid et al., 2010). The sum of these anthropogenic and natural stressors has often had a devastating impact on wetland ecosystems, resulting in a loss of ecosystem services and associated values (Keddy et al., 2009; De Groot et al., 2012).

The EU Water Framework Directive (WFD; Directive 2000/60/EC) recognizes the need to avoid long-term deterioration of freshwater quality and, hence, aims to achieve a “good status” for all surface waters across the European member states by 2015 – implying both a “good ecological status” and "good chemical status". Good ecological status is defined in terms of biological, hydrological and chemical characteristics, and relative to those apparent in conditions of minimal anthropogenic impact for similar systems. Good chemical status is defined in terms of compliance with respect to minimum quality standards for selected chemical substances.

To this end, the WFD requires the definition of Catchment Management Plans (CMPs) – including objectives for all water bodies, justifications for not achieving these objectives, and the program of measures required to meet these objectives. While the implementation of CMPs is known to be costly for farmers, industries and citizens (e.g. Roebeling et al., 2009; Cools et al. 2011; Vinten et al., 2012; Windolf et al., 2012), the associated benefits from improvements in surface water status are less well known (Van Houtven, 2007; Griffiths et al., 2012). Although many studies value the impact of discrete changes in chemical and/or ecological quality of surface waters (e.g. Tumay & Brouwer, 2007; Nallathiga & Paravasthu, 2010; Guimarães et al., 2011; Zhang, 2011), only few studies allow for the valuation of continuous changes in the chemical status of surface waters (e.g. Van Houtven, 2007). There is, however, a lack of studies that consistently assess the environmental-economic benefits/values of continuous changes in surface water status (i.e. chemical and ecological status as defined in the EU Water Framework Directive).

This paper aims to establish a functional relationship between surface water status and (cultural) environmental-economic benefits/values of freshwater systems. To this end we develop an environmental-economic valuation approach, in which we relate the ecological status and chemical status of surface waters (based on local cross-section water quality and Benthic macro-invertebrates survey data) to willingness-to-pay (using benefit-function transfer techniques). A case study is provided for the *Pateira de Fermentelos* freshwater wetland in the Cértima catchment (central Portugal) – estimating the (cultural) environmental-economic benefits/values of the freshwater wetland in its current as well as good status.

THE CÉRTIMA CATCHMENT STUDY AREA

The Cértima catchment is a sub-catchment of the Vouga river basin located in central Portugal, with a catchment area of about 538 km^2 (Figure 1). The Cértima river has a length of about 43 km and, before flowing into the Águeda river, opens-up into the *Pateira de Fermentelos* – a natural freshwater wetland with an area of about 5 km^2 (Maria et al., 2006). The *Pateira de Fermentelos* forms part of the Natura 2000 Network and is considered an important fishing and recreational area (Maria et al., 2006), with eel being the most representative and high economic value fish species and where boating, bird-watching and hiking are the most important recreational activities (CMA, 2013).

Given its specific water dynamics and configurations, the *Pateira de Fermentelos* is predisposed to receive and accumulate contaminants from point (industrial and domestic) and diffuse (agricultural) sources (Teles et al., 2007). Due to the introduction of agricultural fertilisers and pesticides, the increase in population and corresponding urbanization as well as industrialization in the Cértima catchment, the *Pateira de Fermentelos* experienced increased water pollution over the last decades (Maria et al., 2006; Teles et al., 2007). This resulted not only in a thread to fish populations, but also reduced the swimmability of its waters (Teles et al., 2007; Ribeiro, 2012).

METHODS

To estimate the (cultural) environmental-economic benefits/values of improvements in surface water status, an environmental-economic valuation approach is developed that relates:

i. the ecological status (using the freshwater Ecosystem Quality Index, *EQI*; INAG, 2009), and
ii. the chemical status (using the Water Quality Index, *WQI*; Vaughan, 1986)

of surface waters (based on cross-section water quality and Benthic macro-invertebrates survey data; Silva, 2008), to:

iii. Willingness-To-Pay (*WTP*) for improvements in water quality and aquatic ecosystem services (using benefit-function transfer techniques; Van Houtven, 2007).

Ecosystem Quality Index (EQI)

The freshwater Ecosystem Quality Index (*EQI*) represents the relationship between the values observed for a particular biological indicator at a study site, and the corresponding biological indicator value for a reference site of the same type (INAG, 2009). Based on Benthic macro-invertebrates surveys in the Cértima catchment (Silva, 2008), the biological indicator is given by the Portuguese Invertebrate Index for Southern rivers ($IPtI_S$) that is calculated as a combination of several metrics – each one normalized by a value established for a reference site of the same type. In turn, the *EQI* is given by the ratio between the $IPtI_S$ at the study site and the corresponding mean established at the reference sites ($[IPtI_S]_{ref}$), such that:

$$EQI = IPtI_S \Big/ \left[\overline{IPtI_S}\right]_{ref} \qquad (1)$$

and where the *EQI* is expressed in numerical values ranging from 0 (extreme degradation) to 1 (reference condition) (INAG, 2009).

Water Quality Index (WQI)

The Water Quality Index (*WQI*) is a numerical expression that reflects the influence of numerous chemical, physical and microbiological parameters on surface water quality. Based on water quality surveys in the Cértima catchment (Silva, 2008), a modified version of the *WQI* developed by Vaughan (1986) is adopted. The *WQI* ranks water quality according to its use (based on a 10-point water quality ladder), incorporates five parameters (dissolved oxygen [% sat]; biochemical oxygen demand [mg O_2/L]; pH [Sorenson]; nitrates [mg N-NO_3/L]; phosphates [mg P/L]), and is calculated as follows:

$$WQI = \sum_{i=1}^{n} q_i^{w_i} \Big/ 10 \qquad (2)$$

where q_i is the water quality parameter (with $1 < q_i < 100$), w_i is the relative weight of each parameter (with $0 < w_i < 1$) and where n is the number of water quality parameters ($n = 5$) (see Ribeiro, 2012). The *WQI* is expressed in numerical values ranging from 0 to 10, with 0.5 (unacceptable for any use), 2.5 (boatable), 5 (fishable), 7 (swimmable) and 9.5 (drinkable) as qualitative threshold values.

Relating EQI and WQI

Chemical and ecological status are intrinsically related, though do not necessarily coincide in the short term (Munné et al., 2012). Based on the cross-section water quality and Benthic macro-invertebrates surveys in the Cértima catchment (Silva, 2008), we adopt an exponential functional relationship between the *EQI* and *WQI*, given by:

$$EQI = \alpha_1 e^{\alpha_2 WQI} \qquad (3)$$

where α_1 and α_2 are the linear and exponential coefficients, respectively. Provided that $\alpha_1 > 0$ and $\alpha_2 > 0$, Eq. 3 reflects increasing marginal *EQI* improvements from fixed *WQI* changes.

Willingness-To.Pay (WTP)

The Willingness-To-Pay (*WTP*) represents the (cultural) environmental-economic benefits/values of improvements in surface water quality through enhancements in aquatic ecosystem services. Based on 131 stated preference studies (from the US) that describe water quality in terms of the *WQI* developed by Vaughan (1986), we adopt the log-linear *WTP* function estimated by Van Houtven et al. (2007). This *WTP* function is dependent on *WQI* and, following Bateman et al. (2011), household income *INC*, so that:

$$WTP(WQI, INC) = \beta_1 WQI^{\beta_2} INC^{\beta_3} \qquad (4)$$

where β_1 is the linear water quality improvement benefit coefficient, and where β_2 and β_3 are the *WQI* and *INC* elasticity coefficients, respectively. Note that the *WTP* function reflects decreasing marginal benefits from *WQI* and *INC* in case $0 < \beta_2 < 1$ and $0 < \beta_3 < 1$, respectively.

Solving Eq. 3 for *WQI* and subsequent substitution into Eq. 4 gives us the *WTP* function that is dependent on *EQI* as well as household income *INC*, and is given by:

$$WTP(EQI, INC) = \beta_1 \ln\left(\frac{EQI}{\alpha_1}\right)^{\beta_2} \left(\frac{INC^{\beta_3}}{\alpha_2^{\beta_2}}\right) \qquad (5)$$

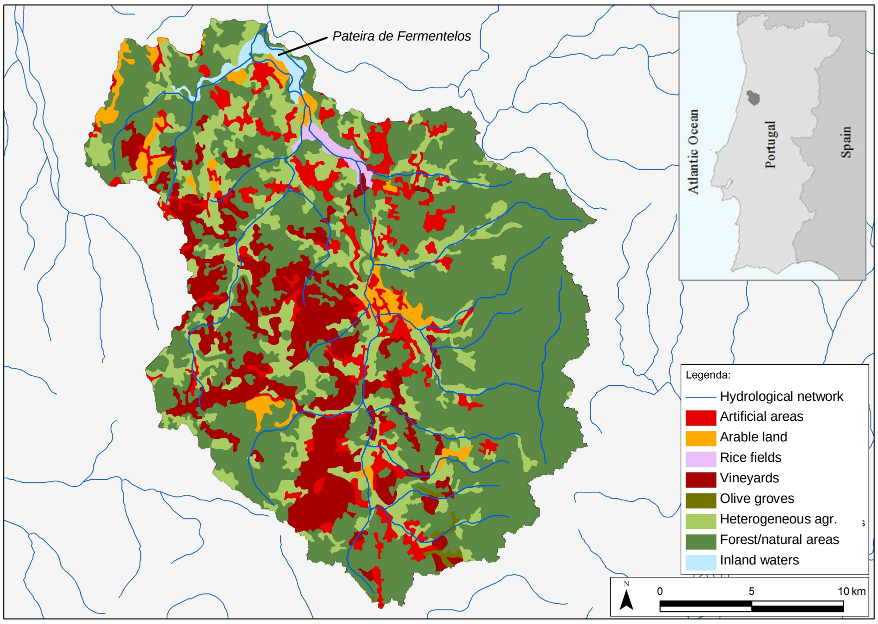

Figure 1. Land use in the Cétima catchment (Portugal). Source: CLC2006 (EEA, 2009).

Again, and for the abovementioned α and β parameter ranges, Eq. 5 implies decreasing marginal benefits from *EQI* and *INC*.

Consequently, we can now estimate *WTP* based on chemical (*WQI*) as well as ecological (*EQI*) status – which is essential given that surface water status, and arguably *WTP*, is determined by the poorer of its ecological and its chemical status (Directive 2000/60/EC).

RESULTS AND DISCUSSION

Results are based on 2010 data. Parameter value estimates for Eq.3 are based on water quality and Benthic macro-invertebrates survey data for the Cértima catchment (Silva, 2008), using Ordinary Least Squares (α_1 = 0.0315 and α_2 = 0.3219; R^2 = 0.77). Parameter values for Eq.4 and 5 are based on Van Houtven et al. (2007; $\beta_{1,\text{users}}$ = 1.057, $\beta_{1,\text{non-users}}$ = 0.352, β_2 = 0.823 and β_3 = 0.897; R^2 = 0.59), and corresponding *WTP* estimates are based on the central Portuguese 2010 household income (*INC* = 10.957 k€ in 2000€; INE, 2013), converted into € using the 2000 US$/€ exchange rate (1.084; OANDA, 2013) and corrected for inflation using the Portuguese Consumer Price Index (2000-2010: 127; World Bank, 2013).

Water quality and Benthic macro-invertebrates data from the *Pateira de Fermentelos* (based on Silva, 2008), show that the current status of surface waters is good from a chemical perspective (*WQI* > 5.5) though only mediocre from an ecological perspective (0.19 ≤ *EQI* ≤ 0.37; see Table 1). *WTP* for this current surface water status (*EQI* = 0.25) is obtained using Eq. 5, and equals 53.8 €/yr for users and 17.9 €/yr for non-users. In order to meet the good status of surface waters as required by the WFD (Directive 2000/60/EC), the *EQI* in the *Pateira de Fermentelos* needs to reach the threshold value of 0.56. This would lead to increase in *WTP* of 16.7 €/yr for users (to 70.5 €/yr) and 5.6 €/yr for non-users (to 23.5 €/yr).

The total number of users of the *Pateira de Fermentelos* in 2010 is estimated at 23,988, based on the number of issued recreational fishing permits for the Cértima catchment (1,879), the number of guests at the *Estalgem da Pateira* hotel (10,109) and the number of Trail-map downloads (12,000) in 2010. The total number of non-users in 2010 is estimated at 14,169, based on the average of ratios users:non-users (63%:37%) found in Bockstael et al. (1989), Nowak et al. (1990) and Farber & Griner (2000). Given the current surface water status (*EQI* = 0.25), the (cultural) ecosystem service value of the *Pateira de Fermentelos* is estimated at 1.54 m€/yr. Meeting WFD objectives (*EQI* = 0.56) would lead to an increase in value of 0.48 m€/yr (to 2.02 m€/yr).

Table 1. Current and good status of surface waters in the *Pateira de Fermentelos* (Cértima catchment, Portugal).

Index	***Range***	***Current status***	***Threshold good status***
WQI	0 – 10	7.5	> 5.5
EQI	0 – 1	0.25	> 0.56

The *Pateira de Fermentelos* is a natural freshwater wetland with an area of about 500 ha (Maria et al., 2006) and, consequently, its estimated value equals 3,087 €/ha/yr in its current status (*EQI* = 0.25) and 4,047 €/ha/yr in its good status (*EQI* = 0.56). These values are somewhat above those found in other studies. Costanza et al. (1997) estimate the total ecosystem service value of wetlands at 23,724 €/ha/yr and the value of lakes/rivers at 13,636 €/ha/yr – the corresponding recreational/cultural ecosystem service values are estimated at 2,335 €/ha/yr and 369 €/ha/yr, respectively. De Groot et al. (2012) estimate the total ecosystem service value of inland wetlands at 16,336 €/ha/yr and the value of rivers and lakes at 2,714 €/ha/yr –

corresponding cultural ecosystem service values are estimated at 2,673 €/ha/yr and 1,378 €/ha/yr, respectively.

CONCLUSIONS

In this study we establish a functional relationship between surface water status and (cultural) environmental-economic benefits/values of freshwater systems, using an environmental-economic valuation approach that relates the ecological status and chemical status of surface waters (based on local cross-section water quality and Benthic macro-invertebrates survey data) to willingness-to-pay (using benefit-function transfer techniques). We contribute to earlier studies by consistently assessing the (cultural) environmental-economic benefits/values of continuous changes in surface water status (i.e. chemical and ecological status as defined in the EU Water Framework Directive; WFD) – hence bridging a prominent gap between bio-physical and socio-economic sciences (Mendelsohn & Olmstead, 2009).

Results for the *Pateira de Fermentelos* freshwater wetland in the Cértima catchment (central Portugal) show that the current status of surface waters is good from a chemical perspective though only mediocre from an ecological perspective. Willingness-To-Pay (*WTP*) for this current surface water status equals 53.8 €/yr for users and 17.9 €/yr for non-users – increasing, respectively, to 70.5 €/yr and 23.5 €/yr in case good status of surface waters is obtained (as required by the WFD; Directive 2000/60/EC). Based on the total number of user and non-users of the *Pateira de Fermentelos*, the current (cultural) ecosystem service value of the *Pateira de Fermentelos* is estimated at 1.54 m€/yr – increasing to 2.02 m€/yr in case WFD objectives are met. The current annual (cultural) ecosystem service value of the *Pateira de Fermentelos* is estimated at 3,087 €/ha/yr – in line with estimates from Costanza et al. (1997) and De Groot et al. (2012).

Some caveats remain. First, this study focusses on the cultural environmental-economic benefits/values of changes in surface water status in freshwater systems only. The total environmental-economic benefits/values of changes in surface water status are, however, much more comprehensive – encompassing numerous ecosystem services across multiple ecosystems (TEEB, 2013). For example: cultural ecosystem service values only account for 10-15% of the total ecosystem service value of wetlands – for lakes and rivers this is 5%-50% (Costanza et al., 1997; De Groot et al., 2012).

Second, the use of locally collected rather than externally transferred data benefits local decision making (TEEB, 2013). Although benefit function transfer techniques are used and, hence, (cultural) ecosystem service benefit/value estimates are based on local parameter values (*EQI*, *WQI* and *INC*), benefit transfer is considered to lead to substantial transfer errors (e.g. Brouwer, 2000). Bateman et al. (2011), however, show that benefit/value function transfers will reduce errors relative to means if transfers involve dissimilarities in provision changes, goods and/or contexts – in particular when benefit transfer functions are based on economic principles and variables for which we have strong prior expectations.

Finally, it may seem counterintuitive that the chemical status and the ecological status of surface waters do not coincide. In their study on 367 Catalan water bodies in Spain, however, Munné et al. (2012) show that over 80% of water bodies achieve good chemical status while only 60% achieve good ecological status – hence confirming that chemical and ecological status do not necessarily coincide in the short term.

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