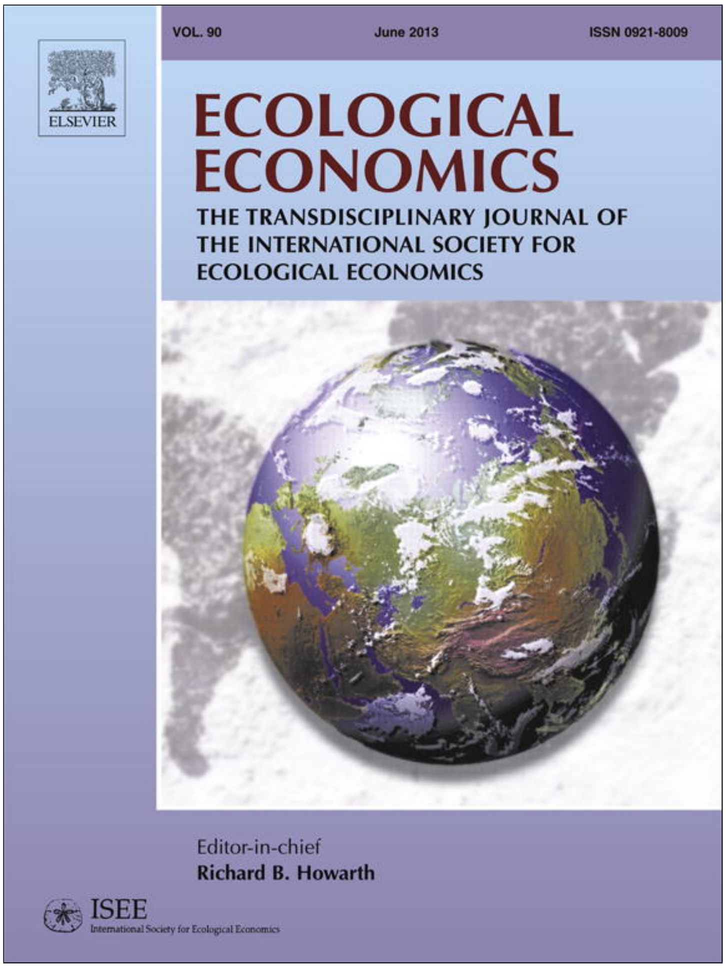
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Analysis

Examining the Demand for Ecosystem Services: The Value of Stream Restoration for Drinking Water Treatment Managers in the Llobregat River, Spain

Jordi Honey-Rosés [a,b,*], Vicenç Acuña [b], Mònica Bardina [c], Nicholas Brozović [d], Rafael Marcé [b], Antoni Munné [c], Sergi Sabater [b,h], Montserrat Termes [e], Fernando Valero [f], Àlex Vega [g], Daniel W. Schneider [a]

[a] Department of Urban and Regional Planning, 111 Temple Buell Hall, 611 Taft Drive, University of Illinois, Urbana-Champaign, Champaign, IL 61820, USA
[b] Catalan Institute for Water Research (ICRA), Edifici H20, Emili Grahit 101 Parc Científic i Tecnològic de la Universitat de Girona, 17003 Girona, Spain
[c] Catalan Water Agency (ACA), c/ Provença 204, 08008 Barcelona, Spain
[d] Department of Agricultural and Consumer Economics, 1301 W. Gregory Dr., University of Illinois, Urbana- Champaign, Urbana, IL 61801 USA
[e] Centre Tecnològic de l'Aigua (CETaqua), Carretera d'Esplugues 75, 08940 Cornellà de Llobregat, Barcelona, Spain
[f] Aigües Ter-Llobregat (ATLL), Sant Martí de l'Erm, 30, 08970 Sant Joan Despí, Barcelona, Spain
[g] Aigües de Barcelona (AGBAR), Avinguda Diagonal 211, 08018 Barcelona, Spain
[h] Institute of Aquatic Ecology, Faculty of Sciences, University of Girona, Campus Montilivi 17071 Girona, Spain

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ABSTRACT

Ecosystem services would be incorporated into decision making more often if researchers were to focus more on the demand for these services rather than the supply. This implies examining the economic, decision making and technological context of the end-user before trying to attribute economic values to well known biological processes. This paper provides an example of how this research approach for ecosystems services could unfold. In the Llobregat River in northeastern Spain, higher stream temperatures require water treatment managers to switch on costly water treatment equipment especially during warm months. This creates an opportunity to align the economic interests of downstream water users with the environmental goals of river managers. A restored riparian forest or an increase in stream flow could reduce the need for this expensive equipment by reducing stream temperatures below critical thresholds. We used the Stream Network Temperature Model (SNTEMP) to test the impact of increasing shading and discharge on stream temperature at the intake of the drinking water treatment plant. The value of the stream temperature ecosystem services provided by existing forests is €79,000 per year for the water treatment facility, while additional riparian forest restoration along the Llobregat River could generate economic savings for water treatment managers in the range of €57,000–€156,000 per year. Stream restoration at higher elevations would yield greater benefits than restoration in the lower reaches. Moderate increases in stream discharge (25%) could generate savings of €40,000 per year.

1. Introduction

The extensive body of research on ecosystem services has not generated a commensurate transformation on how ecosystems are managed in practice. If ideas about ecosystem services are to make a unique contribution to environmental management, the discussion must move from theoretical frameworks to practical applications (Cowling et al., 2008; Daily and Matson, 2008; Daily et al., 2009; Muradian et al., 2010). We argue that ideas about ecosystem services would be more widely adopted if researchers were to focus on the demand for ecosystem services rather than their supply. This demand-oriented approach implies inverting the sequence in which linkages between ecological and economic systems are frequently studied. The approach would begin with the end users, their policy objectives, or decision making and technological context. This starting point is more likely to uncover opportunities for the management of ecosystem services and the implementation of these ideas by resource managers.

At its core, the field of ecosystem services studies the linkages between economic and ecological systems (MA, 2005; NRC, 2005). However this inquiry often begins with the ecological or biophysical (Chan et al., 2006; Kremen and Ostfeld, 2005; Naidoo et al., 2008). Often researchers will define the ecological site of interest – a protected area, a forest ecosystem, a watershed, or a river corridor – and then identify the range of services supplied by these areas, such as flood protection, recreational values or spiritual values. Questions concerning economic valuation are left to the end, so by the time economists commence the valuation exercise, the ecosystem scale

* Corresponding author at: School of Community and Regional Planning, University of British Columbia 433-633 Memorial Road, Vancouver, BC V6T 1Z2 Canada. Tel.: +1 (604) 822 3276.
E-mail address: jhoney@post.harvard.edu (J. Honey-Rosés).

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and end-users have either been pre-determined or are only vaguely identified as “society”. This sequence can lead to poorly targeted research, sub-optimal management or controversial valuation estimates (Sangenberg and Settele, 2010).

The most advanced applications of the ecosystem services concept can be observed in programs that pay for environmental services (PES). PES programs have been created in diverse contexts around the world including China, Costa Rica, Mexico and France (Gong et al., 2010; Honey-Rosés et al., 2009; Muñoz-Piña et al., 2008; Pagiola, 2008; Perrot-Maître, 2006). Yet in a review of PES programs globally, it has been found that most PES projects are funded by third parties such as governments or international agencies rather than the beneficiaries themselves (Ortega-Pacheco et al., 2009; Wunder et al., 2008). User-financed PES programs, in which the beneficiaries of the ecosystem service pay the service providers directly, remain rare. The limited number of user-financed PES programs is partially the result of projects being conceptualized from the supply side, or the ecosystem needing protection — rather than the demand, or the ecosystem users. In Spain, PES programs are still in their early stages of conceptualization (Russi, 2010), and their development is likely to build on existing research on environmental markets and market based approaches to resource distribution and management (Goetz et al., 2008; Honey-Rosés, 2009).

In this paper we contend that ideas about ecosystem services would be more widely adopted if we studied the management objectives that ecosystem services could help us achieve. However to do so, we must understand the context in which decisions are made and how ecosystems may generate value. This decision making context may then guide our inquiry, and help us identify services provided by ecosystem structures and functions. This demand-oriented approach directs our attention to the needs of resource users first, and then seeks to show that the interests of resource users and managers may be aligned. This differs from how many ecosystem service projects or PES projects are conceived because attention is first directed at the user of the ecosystem prior to studying the ecosystem itself.

This paper provides an example of how this research approach for ecosystem services could unfold. Water users at the Aigües Ter-Llobregat (ATLL) water treatment facility in Abrera, Spain, treat surface water from the Llobregat River to supply the Barcelona metropolitan region. Treatment managers rely on stream temperature to guide major operation decisions. As stream temperatures rise in the spring and summer, water managers progressively turn on electrodialysis reversal (EDR) treatment modules (Valero and Arbós, 2010). EDR modules must be added because warmer water accelerates the formation of harmful disinfection by-products during the treatment process (ATLL, 2008; Sorlini and Collivignarelli, 2005; Villanueva-Belmonte, 2003). The additional EDR modules ensure that the output water quality will comply with drinking water legislation during warmer months (ATLL, 2008; Valero and Arbós, 2010). As a result of these treatment protocols, a reduction in stream temperatures would reduce the number of days in which the expensive EDR modules would be needed.

Direct solar radiation and air temperature are the primary determinants of stream temperature, although the river also captures heat generated from friction with the stream bed, and long wave radiation emitted by surrounding topography and vegetation. Streams are generally coolest at their headwaters and then temperatures rise as water moves downstream, rapidly at first, and then more slowly at lower elevations. Urbanization, deforestation and water withdrawals also contribute to thermal heating in streams (Webb et al., 2008). In contrast, hypolimnetic water releases from dams usually cool streams. River managers can alter stream temperature by restoring riparian forests that block direct thermal radiation, by increasing stream discharge, or by restoring stream meanders and surface-subsurface interactions.

Thermal heating in rivers and streams can disrupt important ecological processes (Johnson, 2003; Webb et al., 2008). Warmer waters may limit fish reproduction, accelerate ecological metabolism, and increase the vulnerability of aquatic life to disease (Acuña and Tockner, 2009). Temperature also plays an important role in determining the availability of dissolved oxygen for freshwater organisms. Low levels of dissolved oxygen during summer months are associated with major fish kills (Graczyk and Sonzogni, 1991).

The modeling of stream temperature has been widely used to predict the potential effects of management practices (Bartholow, 1991; Chen et al., 1998; Bartholow, 2000a, 2000b; Watanabe et al., 2005). Aquatic ecologists originally developed stream temperature models to study habitat suitability for fish, particularly in the Pacific Northwest of the United States where Federal and State agencies have regulated maximum stream temperatures to protect endangered salmon (Cassie, 2006; Webb et al., 2008). Most stream temperature studies use deterministic models that calculate the total heat fluxes in the river system. Others have used models based on regression techniques in which air temperature is the primary input parameter; or stochastic modeling methods that separate annual temperature cycles from short-term components (Cassie, 2006). Temperature models that rely on calculations of the stream's heat budget allow model users to evaluate the effects of altered conditions affecting solar radiation.

Riparian forests moderate water temperatures by protecting the river from direct sunlight (Bartholow, 1989; Beschta, 1997; Larson and Larson, 1996). Yet the precise impact of stream shading on stream temperature varies with baseline conditions, vegetation height, latitude, and stream discharge. These contextual differences make it difficult to compare shading's impact on stream temperature even when values are translated into temperature reductions per kilometer.

Nevertheless, a few examples are illustrative. In the Cache la Poudre River, Colorado it has been estimated that the increasing shade from 13% to 23% would reduce maximum temperatures in the summer by approximately 1.25 °C over a 32 km reach (0.04 °C/km) (Bartholow, 1991). In contrast Seedang et al. (2008) estimated that shading decreased maximum temperatures by less than 1 °C (0.01 °C/km) in a 92 km reach in the upper main stem of the Willamette River, Oregon. The authors hypothesize that the voluminous discharge and wide stream width prevented shading from altering stream temperature.

Increasing stream discharge is another management practice that may mitigate thermal heating. Again in the Cache la Poudre River, Colorado, it was estimated that increasing discharge by 3 m^3/s (300%) would allow the reach to comply with temperature requirements year round (Bartholow, 1991). In contrast, Seedang et al. (2008) found that increasing discharge in the upper main stem of the Willamette River had limited impact on temperature.

In this study we used a deterministic stream temperature model to explore how ecosystem services associated with river shading and discharge might reduce stream temperatures at the intake of a drinking water facility in Abrera, Spain. This allowed us to avoid measuring all ecosystem services provided by the Llobregat River, such as nutrient cycling, water provision, or flood protection, and instead target those services for which there is a known demand from specific water users.

2. Study Area

The Llobregat River flows 170 km in a southward direction from its headwaters in the Pyrenees Mountains to the Mediterranean Sea (Fig. 1). The upper segments of the Llobregat watershed receive 1000 mm of precipitation per year while the mid section of the watershed is considerably drier with only 400 mm per year (Mujeriego, 2006). The Llobregat River has an annual discharge of 660 hm^3 although its flow regime is highly variable. The Llobregat has one major tributary, the Cardener River, which is slightly smaller in size when the two rivers join at mid-watershed.

The Llobregat River provides the Barcelona Metropolitan Region (pop. 3.5 million) with 45% of its drinking water supply (Mujeriego, 2006). Approximately one quarter of the metropolitan region's water

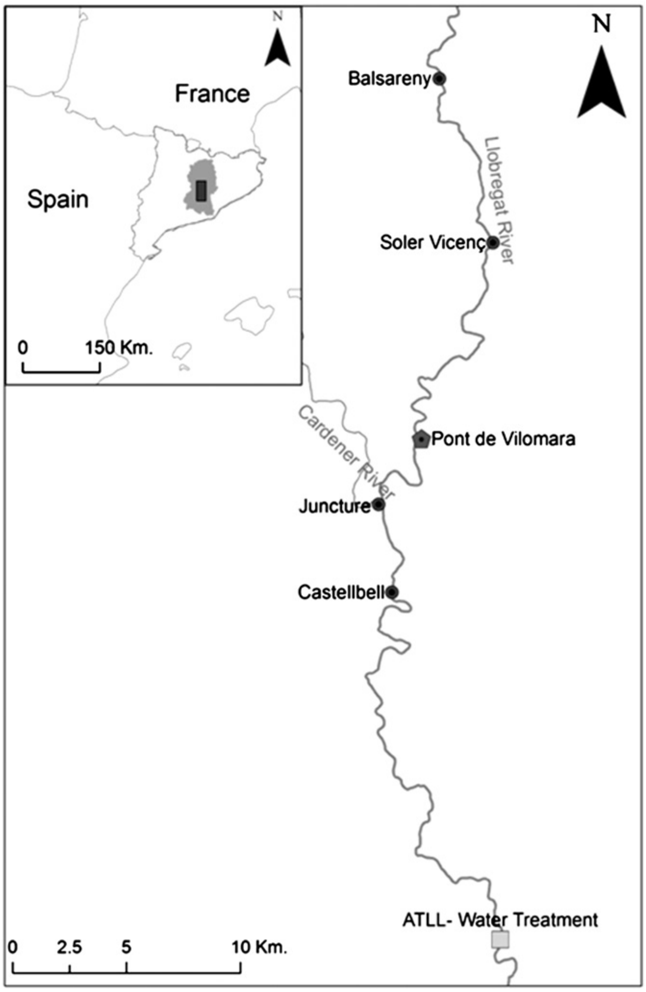


Fig. 1. The study reach is 57.6 km, starting at the town of Balsareny to the ATLL drinking water treatment facility in Abrera. Meteorological data was collected from a weather station at Pont de Vilomara.

is treated at the ATLL treatment facility in Abrera (max. capacity = 4 m^3/s). On average, the ATLL treatment facility treats at a rate of 2.5 m^3/s. The volume treated usually increases in the Spring and Fall and decreases during the Summer. The average discharge flowing past the ATLL facility is 8 m^3/s although flow is highly variable. In 2009 a total of 401 hm^3 flowed past the ATLL water treatment facility (30% above average). Two major dams hold back the Llobregat and the Cardener Rivers before they leave the Pyrenees Mountains. The size of the hypolimnetic releases from the dams is negotiated periodically between the hydroelectric dam operators, water suppliers and the regional water agency of Catalonia.

The study reach consists of 57.6 km between the stream gage at Balsareny, downstream of the lowermost dam, and the ATLL water treatment facility in Abrera (Fig. 1). The entire river network could not be modeled because of the presence of the dams. The Llobregat River travels 27.8 km between Balsareny and the confluence with the Cardener. The river then travels another 29.8 km to the ATLL water treatment facility, located 29.0 km upstream from the river's mouth in the Mediterranean.

2.1. SNTEMP Model

The Stream Network Temperature Model (SNTEMP) is a one-dimensional heat transport model for stream networks that predict mean daily water temperatures based on heat flux equations (Bartholow, 2000a, 2000b; Theurer et al., 1984). The mechanistic model was originally developed by the U.S. Fish and Wildlife Service (Theurer et al., 1984) and is now distributed by the United States Geological Survey (USGS). USGS has generated training materials for SNTEMP which has facilitated its widespread use (Hendrick and Monahan, 2003; Norton and Bradford, 2009). SNTEMP is a well characterized and tested model that can evaluate changes in both stream shading and discharge, with only moderate data requirements. The model calculates the heat gained or lost from a parcel of water as it passes through the various nodes in a stream network. The model simulates heat flux processes of convection, conduction, evaporation, direct solar radiation (short wave), atmospheric radiation, radiation from riparian vegetation (long wave), and back radiation released by the water (Bartholow, 2000a, 2000b). The model requires data on stream hydrology, stream geometry, meteorology and shading conditions (Table 1). Given these inputs, the model predicts the stream temperature at the end of the segment. The stream network model was constructed using 22 nodes, each of which marks either a change in stream temperature, discharge, geographic or shading conditions or thermal mixing (Fig. 2).

2.2. The Llobregat River SNTEMP Model

We obtained meteorological data from the Catalan Meteorological Service that operates a weather station located at the center of the stream segment (km 37) in the town of el Pont de Vilomara (406310, 4617994 UTM) (Fig. 1). Hydrologic and stream temperature data were obtained from the Catalan Water Agency (ACA). A complete data set for all nodes was available for the 2009 calendar year.

We measured vegetative and topographic shade on 8 and 9 May 2011 following the field work guidelines outlined in Bartholow (1989). The field work allowed us to measure stream width, vegetation height, density and offset in the 15 stream segments. Vegetation density varied between 10% and 80%, while stream width varied between 20 and 60 m. We verified the location of stream gages, diversions, returns and point sources, and identified sites where the properties of the stream changed (C nodes). We also evaluated if the restoration of riparian forests was viable given current soil quality or topographic conditions. We annotated the location of sites where extreme slopes (cliffs), or the absence of soils (large stones and boulders) would make any proposal to reforest unrealistic. Forest coverage estimates collected in the field were compared with satellite imagery available from Google Earth. In stream segments where field measurements were not taken we relied on satellite imagery for estimates of vegetation density and stream width.

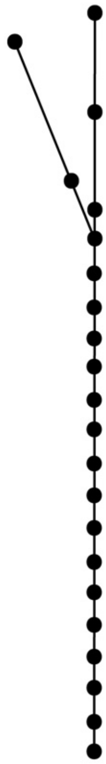
2.3. Shading Scenarios

We divided the Llobregat into multiple segments according to topographic and forest conditions. We defined a stream segment as "restorable" if it had less than 30% forest cover along its bank and did not have an obvious impediment to forest restoration such as poor soil quality, or steep topography.

We tested five shading scenarios. The first three scenarios increased shade only in the subset of river segments defined as "restorable" (<30%

Table 1
Input data requirements for the SNTEMP Model.

Stream Hydrology	Stream Geometry	Meteorology	Shading Conditions
Segment Inflow	Node Latitude	Mean Daily Air Temp	Topographic Shade
Temperature Inflow	Node Elevation	Relative Humidity	Vegetation Shade
Segment Outflow	Width A and B Terms	Wind Speed	
Accretion Temperature	Manning's N	Solar Radiation	
		Ground Temperature	
		Thermal Gradient	



	Node	Distance (Km)	Elevation (m)
Headwaters Llobregat (Balsareny)	H	57.6	285
Headwaters Cardener (Castellgalí)	H	32.0	175
Change in stream properties Soler Vicenç	C	49.1	175
Tributary Cardener	T	29.8	165
Branch Llobregat	B	29.8	165
Juncture Cardener	J	29.8	165
Discharge Castellbell	Q	23.9	148
Change in stream properties Burés	C	23.0	141
Change in stream properties Borràs C.	C	21.8	141
Change in stream properties La Bauma	C	20.5	132
Change in stream properties La Bauma D.	C	19.6	127
Point Discharge. WWTP Castellbell i el Vilar	P	19.5	127
Change in stream properties C58	C	18.9	125
Change in stream properties Puig i Font	C	17.8	125
Change in stream properties Montserrat	C	16.9	119
Point Discharge. WWTP Monistrol	P	15.1	109
Change in stream properties Cairat	C	11.0	80
Change in stream properties La Puda	C	9.8	75
Change in stream properties Can Sedó	C	6.8	70
Change in stream properties Final Turn	C	3.0	63
Diversion Aigües de Terrassa	D	2.6	62
End. ATLL Treatment Plant Abrera	E	0	57

Fig. 2. A schematic representation of the modeled stream network between Balsareny and the ATLL drinking water treatment facility in Abrera, Spain. Data on stream discharge was input at the Headwaters (H), Point Discharges (P), and End (E) nodes. Temperature data was input at Headwaters (H), Tributaries (T), Branch (B), and Point Discharges (P) nodes.

cover and favorable soil quality and topography). Shading was increased from its existing condition (<30%) to 40%, 60% and 80% forest cover. The next shading scenario increased shade for the entire stream segment to 100% coverage. This scenario serves as an upper boundary estimate of shading's potential impact. In the final scenario, we removed all existing riparian forest to estimate the contribution of current shade in moderating stream temperatures.

2.4. Discharge Scenarios

We tested five discharge scenarios that increased stream flow by 5%, 25%, 50%, and 100% of historic monthly means. Monthly mean discharge values were computed from a historic data set of six years (2004–2009).

2.5. Model Calibration

The calibration of predicted to observed temperatures was accomplished by adjusting calibration parameters built into the model and following recommended procedures (Bartholow, 1991). In this case we only adjusted the coefficient for air temperature across seasons. During winter months, from November to February, the air temperature calibration coefficient was 0.25. During the peak summer months of June to September it was 0.9. In the remaining months the air temperature calibration coefficient was 0.5. While it was important to ensure that the model's predictions approximated observed outcomes, the relative impact of various management scenarios on stream temperature was the more important measure.

2.6. Value of Ecosystem Services

Managers at the ATLL treatment plant begin to add EDR modules in March of each year when stream temperatures surpass 12 °C. At peak summer temperatures up to nine EDR modules may be turned on. One EDR module is in operation year round, and there are eight additional modules that may be added in warm months. This generates eight temperature thresholds in which the costly EDR treatment modules are added. In this study, we assumed a decision rule in which one EDR module is added for every 2 °C rise in temperature beyond 12 °C (14°, 16°, 18°, etc.) (ATLL, 2008), an assumption that water treatment managers agreed was a reasonable simplification of a decision rule that in practice, makes exceptions for a variety of technical, economic or political reasons. Each module consumes approximately 12,000 kWh per day for a cost of €1,000/day. Value is generated when ecosystem processes delay the exceedance of one of the eight temperature thresholds by at least one day and therefore allow water treatment managers to avoid turning on an additional EDR module.

2.7. Riparian Reforestation Costs

We collected information on riparian restoration projects in order to estimate the costs associated with the increasing stream shade along the Llobregat Rivers and conduct a cost-benefit analysis of the restoration projects over a 20 year period. ACA has financed projects that remove invasive species of cane (*Arundo donax*) and replaced them with native species of Willow (*Salix alba*), Ash (*Fraxinus angustifolia*) and Poplar (*Populus Alba*). These projects were executed along the Llobregat and Cardener Rivers, and therefore offer a useful precedent to help gage future restoration costs (Illa-Antich et al., 2010, 2011). Trees are planted as seedlings and are expected to reach full maturity after 20 years. Given the initial investment, we calculated the net present value of the project over a 20 year period with a discount rate of 4%. Since we cannot expect that the full benefits associated with shading will materialize until the trees reach maturity, we estimated annual savings that were proportional to the growth rate of riparian trees (Watanabe et al., 2005).

2.8. Robustness Tests

The SNTEMP model has already been validated (Bartholow, 1991, 2000a, 2000b), however the model does not provide users with estimates of uncertainty or error. Therefore we manually tested the robustness of our results to assumptions concerning estimated parameters (Manning's N) and measurement error (relative humidity, stream width, vegetation height). In the stream shading scenarios, we modified relative humidity (+/−10%), stream width (+/−20%), vegetation height (+/−25%) and tested Manning's N at 0.045 and 0.025. For the stream discharge scenarios, we re-calculated the results with changes in relative humidity (+/−10%), stream width (+/−20%) and vegetation height (+/−25%). The percent +/− variation was chosen to approximate the maximum potential deviance, and therefore serves as an upper and lower boundary of expected error. We also tested for robustness to assumptions pertaining to model calibration and to the placement of EDR thresholds.

3. Results

SNTEMP produced satisfactory water temperature predictions during the spring, summer and fall of 2009 ($R^2 = 0.93$, N = 255, Pearson correlation = 0.94) (Fig. 3). The calibrated model predicted stream temperatures with a mean error of 0.53 °C, overestimating observed temperature. Forty percent of the model's predictions fell within 1 °C of the observed value. The maximum error was 4.6 °C. To remove the effects of this systematic overestimate in our valuation of ecosystem services, we regressed modeled versus observed temperature and adjusted model output accordingly (Fig. 4).

3.1. Effect of Shading and Discharge on Temperature

An increase in shade over the Llobregat River showed reduced temperatures throughout the stream segment, while the scenario in which all vegetation was removed increased water temperature. Shade produced a stronger effect in warmer months (Fig. 5). The most modest shading scenario (restorable areas to 40%) reduced mean annual stream temperature at the intake of the ATLL water treatment facility by 0.34 °C (0.006 °C/km), while recovering 100% of forest coverage on all segments showed a mean annual reduction of 1.84 °C (0.03 °C/km). The removal of existing riparian vegetation increased stream temperature at the ATLL treatment plant by over 0.5 °C between May and October.

Increasing stream discharge also reduced stream temperature. A 5% increase in discharge had a very small effect on stream temperature (mean reduction = 0.048 °C), whereas a 25% increase in discharge reduced temperature 0.2 °C during warm months (Fig. 5). An increase in discharge by 50% reduced stream temperatures by 0.4 °C during warm months. The doubling of discharge (100%) had a greater effect in the spring and fall, when stream discharge is largest. We hypothesize that the doubling of discharge in the summer made little difference because the summer base flows are already small.

3.2. Longitudinal Temperature Profile

The simulated reductions in stream temperature could prevent the Llobregat River from crossing temperature thresholds, and therefore save water managers from adding EDR modules on particular days. Each day in which water managers avoid adding an additional EDR module would save them €1000. The temperature profile on a particular day allows us to visualize the induced changes in stream temperature projected by each management scenario. For example, on 26 August 2009, one of the warmest days of the year, the stream temperature rose rapidly in the first half of this segment and then more gradually between Castellbell (km 24) and the ATLL treatment plant (Fig. 6). On this day modest changes in riparian shading and discharge were insufficient to maintain stream temperatures below the threshold of 26 °C. Only the most aggressive measures, such as the doubling of discharge or restoring 100% coverage would have kept temperatures below the threshold. In contrast, removing existing vegetation would have increased stream temperature to 27.72 °C at the intake of the ATLL water treatment plant.

On other days, modest management actions were sufficient to prevent the stream temperature from exceeding decision thresholds. For example increasing forest cover to 40% in restorable areas would have reduced stream temperature by 0.45 °C on 25 May 2009 and maintained stream temperature below the 20 °C threshold at the end of the segment (Fig. 6). For this date, then, water managers would have operated without an additional EDR module, saving them €1000 in this management scenario.

In both longitudinal profiles, temperatures rose faster in the first half of the stream segment, between the stream headwaters and the confluence with the Cardener (29.8 km). This rapid thermal heating

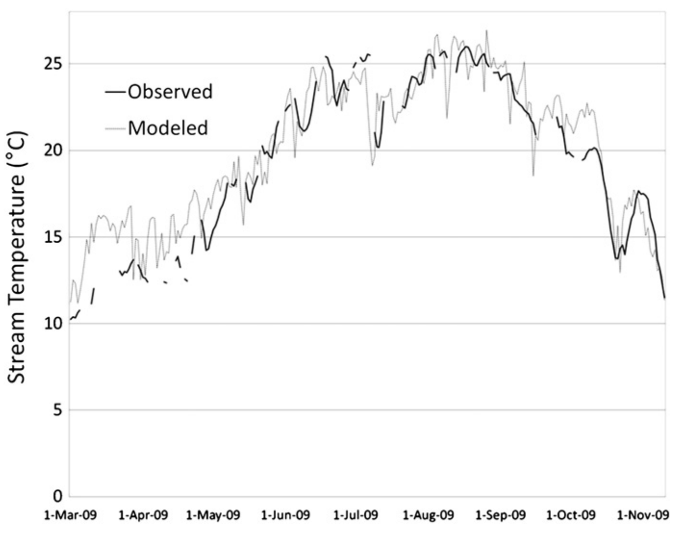


Fig. 3. Observed and predicted temperature values for the Llobregat River during the warmer months of 2009 in which EDR modules are in operation at the drinking water facility.

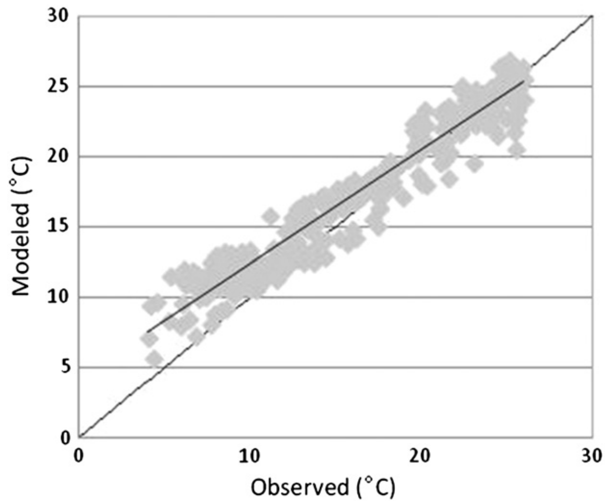


Fig. 4. Observed and modeled temperatures for all dates in 2009. EDR water treatment modules are only used when temperatures surpass 12 °C. At these warmer temperatures the SNTEMP model better predicts observed temperature ($R^2 = 0.933$) T = 0.8068 (observed temp) + 4.335.

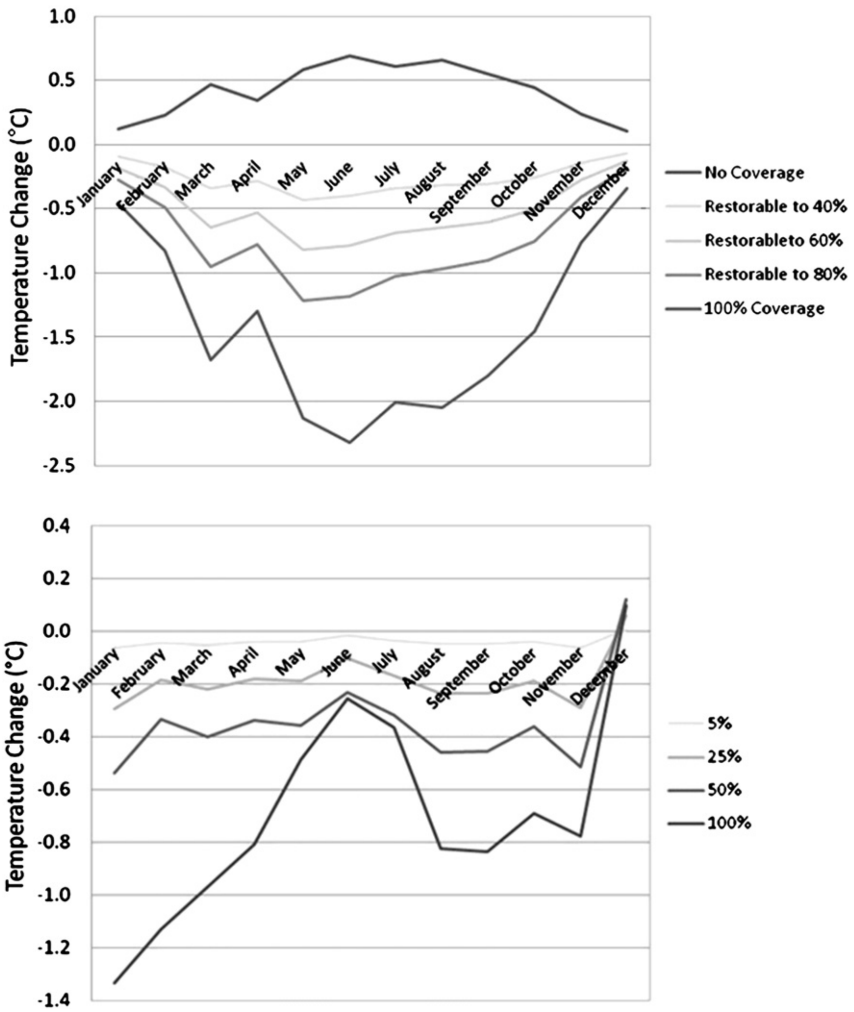


Fig. 5. Mean monthly temperature changes simulated by SNTEMP in the various management scenarios. Top panel: Shading scenarios: (1) existing vegetation coverage removed, (2) riparian forest in restorable areas increased to 40% coverage, (3) riparian forest in restorable areas increased to 60% coverage, (4) riparian forest in restorable areas increased to 80% coverage, (5) 100% coverage in the entire stream reach. Bottom panel: Mean monthly temperature changes simulated by SNTEMP in the four discharge scenarios: (1) increasing discharge 5% of monthly mean, (2) 25% of monthly mean, (3) 50% of monthly mean, and (4) 100% of monthly mean.

in the upper parts of the watershed has also been found elsewhere (Chen et al., 1998).

3.3. Avoided Threshold Crossings

As expected, large increases in shade and discharge are predicted to prevent more threshold crossings, and therefore more reductions in water treatment costs. The shading scenarios would prevent between 57 and 283 threshold crossings, while the discharge scenarios would prevent between 7 and 120 threshold crossings.

3.4. Ecosystem Services Associated With Stream Shading

By adding the number of days in which threshold crossings are prevented, the five shading scenarios could generate savings in the range of €57,000 to €283,000 per year (Table 2). Considering that the ATLL water treatment plant produces approximately 58 million cubic meters annually, this represents a savings of 0.001 €/m^3 and 0.0049 €/m^3. Our model also allowed us to quantify the value of the services provided by the existing vegetation, which is estimated by the scenario in which vegetation is removed. Removing the existing vegetation would require treatment managers to switch on EDR modules an additional 79 days during the year, for an annual cost of €79,000 (0.0014 €/m^3).

3.5. Ecosystem Services Associated With Increased Discharge

Increasing stream discharge by 5% had a nearly negligible impact on stream temperature, preventing threshold crossings on only 7 days for a savings of €7000 annually (0.0001 €/m^3). In contrast a 25% increase in discharge would prevent 40 threshold crossings per year, saving the drinking water facility €40,000 annually. Increasing discharge by 50% would prevent threshold crossings on 75 days, saving water treatment managers €75,000 annually, while the doubling of discharge (100%) would prevent threshold crossings on 120 days, saving water treatment managers €120,000 annually (0.0019 €/m^3) (Table 2).

3.6. Forest Restoration Projects

Past restoration projects along the Llobregat and Cardener Rivers suggest that restoration costs are approximately €120,300 per kilometer (both sides), or €6.02/m^2. At this rate, the restoration cost for each scenario is €1,082,700; €1,624,050; €2,165,400 and €3,464,640 respectively when planting on a 10 m width for each side. These upfront investment costs would be partially recovered through savings in reduced water treatment costs. In each of the restoration scenarios, at least one third of the initial investment is recovered within a 20 year period (Table 3). The most ambitious restoration scenario recovered 52% of the investment. Each of these projects would have

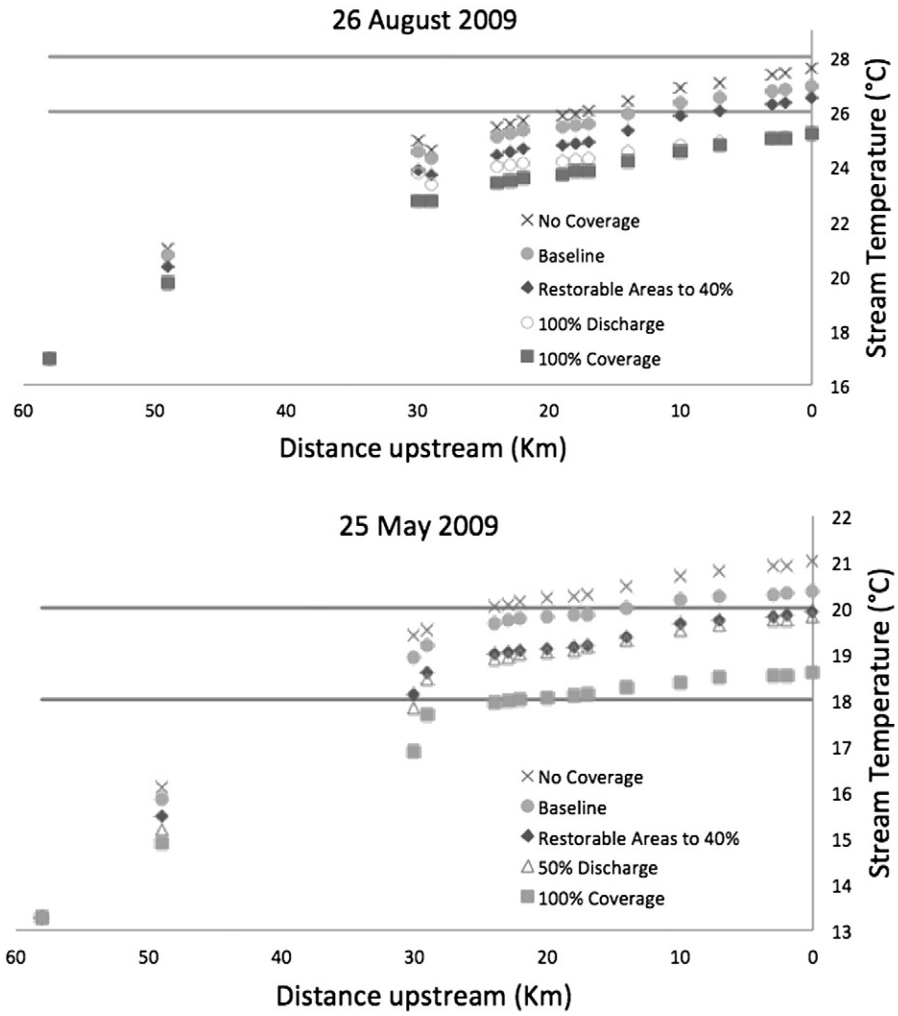


Fig. 6. The temperature profiles of the Llobregat River with simulated management scenarios. The horizontal lines represent temperature thresholds for the water treatment facility. In the top panel, on 26 August 2009, few scenarios reduce stream temperature reduction below the critical threshold. However on this day we observe a cooling effect at the confluence with the Cardener River at km 29. In the bottom panel, on 25 May 2009, more modest management scenarios are able to reduce temperature below the threshold, and therefore provide savings to water treatment managers.

a positive net benefit in 20 years if restoration costs could be lowered to €20,000 per kilometer, or €2.0/m^2.

3.7. Increases in Discharge

Dam releases from two reservoirs upstream (Sant Ponç and Baells) in the Llobregat watershed could increase water flow at a low cost. Moreover, in contrast to riparian restoration, the reductions in stream temperature associated with dam releases would materialize immediately. The critical tradeoff is the loss of water storage. When water supplies are low, the dam releases may not be a viable option. But if temperatures are rising and water supplies are abundant, dam releases may be an effective measure to postpone the use of expensive EDR water modules and produce cost savings in water treatment.

Table 2
The value of ecosystem services for the ATLL water treatment plant for increases in stream discharge and the restoration of riparian forests.

Discharge Scenarios		Shading Scenarios	
Increase in Discharge	Social Benefits	Increase in Shading	Social Benefits
5%	€ 7,000	Restorable Areas to 40%	€ 57,000
25%	€ 40,000	Restorable Areas to 60%	€ 104,000
50%	€ 75,000	Restorable Areas to 80%	€ 156,000
100%	€ 120,000	100% Coverage	€ 283,000
		No Coverage	(€ 79,000)

3.8. Sensitivity Analysis and Robustness Checks

When testing the sensitivity of temperature predictions to changes in humidity, stream width, and vegetation height, the mean annual temperature values changed modestly, and always within 1 °C. As expected, the predicted values were always bounded within the higher and lower estimates (+/−). Temperature predictions were most sensitive to changes in humidity (Honey-Rosés, 2012).

We also tested if the results were sensitive to the placement of thresholds at particular temperature values. Recall that the temperature thresholds for adding an additional EDR model were distributed uniformly every 2 °C above 12 °C (12 °C, 14 °C, 16 °C, 18 °C, 20 °C,

Table 3
Summary of restoration costs and % investment recovered after 20 years.

Shading Scenarios	Segment (km)	Cost (€)	% Investment Recovered
Restorable Areas to 40%	18	€ 1,082,700	33%
Restorable Areas to 60%	27	€ 1,624,050	41%
Restorable Areas to 80%	36	€ 2,165,400	46%
100% Coverage	57.6	€ 3,464,640	52%

22 °C, 24 °C, 26 °C). Therefore we tested how the results might change if these thresholds were 1 °C lower as well as thresholds that were randomly generated (12.8 °C, 13.9 °C, 15.7 °C, 18.6 °C, 21.8 °C, 22.4 °C, 23.7 °C, 24.7 °C). The results were not sensitive to these changes, suggesting that even if water managers modify the temperature thresholds for turning on EDR modules, the value of the ecosystem services is unlikely to change significantly. The economic values predicted with the uncalibrated model were also similar to the values in the calibrated model, and within the boundaries of our other sensitivity analysis (Fig. 7).

4. Discussion

The existing stream vegetation along the Llobregat River already provides valuable ecosystem services for the ATLL water treatment plant, and by extension, for the residents of Barcelona, by maintaining the Llobregat River cool and avoiding the use of EDR modules on approximately 79 days per year, saving €79,000 per year in water treatment costs. Restoring the Llobregat River with more riparian trees or increasing discharge could provide even greater benefits.

The least ambitious shading option would generate services worth €57,000 per year, while the most ambitious scenario, the restoration of vegetation along the entire stream segment (100% coverage), could save water managers €283,000 per year. This last scenario serves as an upper boundary estimate and also shows that ecosystem processes have the potential to generate substantial value for downstream users.

Increases in stream discharge also have the potential to generate additional savings for water treatment managers. The timing of discharge increases is particularly important. Greater flows are most likely to reduce stream temperature in the months of March, April, May, August, September and October.

These results have implications for water managers in Catalonia as they seek to comply with the European Union's Water Framework Directive (WFD) that requires all water bodies to obtain “good ecological status” (Directive, 2000). In an effort to comply with the WFD, the Catalan Water Agency (ACA) has drafted a plan of measures, published in 2010, that budgeted a total of €8.67 million for riparian restoration along the Llobregat River from 2006 to 2015 (ACA, 2010). This research shows that some of these costs can be recovered through reduced water treatment costs. While the benefits accrue directly to ATLL, this is a public agency intimately linked to the Catalan Water Agency (ACA). ACA is responsible for establishing management criteria while ATLL is responsible for operational processes. As a public service, a reduction in water treatment costs will benefit taxpayers because the saved public resources can be reinvested to restore river integrity and other requirements to achieve WFD targets. The social benefits generated by restoration policies provide useful information for policy makers to consider as they must decide which measures to execute and which measures might be postponed because of their financial cost. Governments may be exempt from the European Union's requirement to restore water bodies to “good ecological status” if they can justify that the costs associated with ecological restoration are disproportionately large. However these economic assessments frequently only focus on the costs of the restoration measure and not the associated environmental and economic benefits, as presented here. Therefore this research helps quantify some of the benefits associated with ACA's watershed plan. At the same time, the WFD seeks to invert our economic logic by putting the objective of “good ecological status” at the center of policymaking. Following this logic, the restoration benefits quantified in this paper are in addition to our policy objective of “good ecological status” — rather than a justification for them.

The model does not include the inputs from all waste water treatment plants along this river segment. However when two waste water treatment plants were included in the lower reach they had a negligible impact on downstream temperature (Honey-Rosés, 2012). The model also does not consider the effect of successive river impoundments which hold back the water on its journey between Balsareny and Abrera.

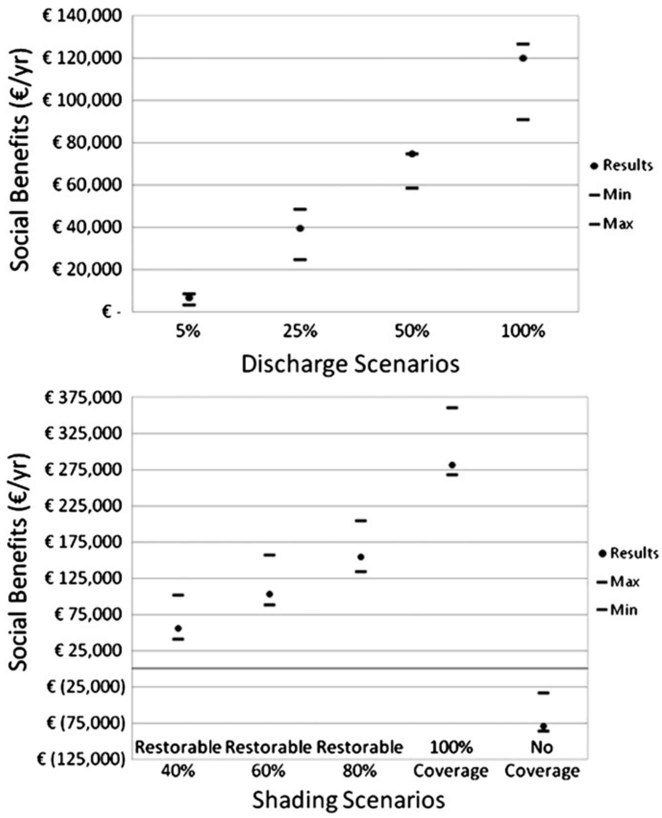


Fig. 7. The upper and lower boundary results in the discharge and shading scenarios when testing for possible error in model calibration, relative humidity (+/−10%), stream width (+/−20%), vegetation height (+/−25%), and Manning's N (0.0025 & 0.0035).

Nor does the model consider the potential reductions in stream discharge that are likely to result from the evapotranspiration of restored forest vegetation along the stream. We tested the shading scenarios with a 5% reduction in stream discharge in order to simulate the effect of evapotranspiration, and in each case the model predicted larger ecosystem service values.

The longitudinal profiles suggest the location of riparian shading matters. In this case, increasing shading at higher elevations was more likely to maintain waters cool. Downstream, in contrast, shading had a smaller cooling effect presumably because stream temperatures had already risen (Honey-Rosés, 2012). If managers were to reforest along the river corridor with the explicit intent of reducing stream temperatures, these findings suggest that it would be more effective to target stream segments at higher elevations. Other studies have also found that shading closer to the headwaters is more effective at reducing stream temperatures (Chen et al., 1998).

None of the restoration scenarios could offer projects with a positive net present value after 20 years because of the high initial investment and low initial returns that do not become significant until the trees reach full maturity. If the restoration projects were to plant older trees they would provide more benefits earlier, and the projects would have higher returns. A drop in restoration costs, not unreasonable given the current economic downturn in Spain, would also shorten the time in which the investment could be fully recovered.

Increasing stream flow through strategic dam releases would allow water managers to realize benefits within a shorter time frame. However, water must be stored strategically in reservoirs and managed to ensure continuous water provision during dry periods. Also, these releases would need to be negotiated with the Catalan Water Agency and the electrical company that captures energy from the hydroelectric dams. The institutional structures already exist to allow this negotiation to develop. Increasing stream discharge would be most realistic when reservoirs are near full capacity. For example, if reservoirs were full in late May due to spring rains, and temperatures were to rise abruptly, the reservoir releases could help maintain stream temperatures cool, and prevent the ATLL treatment plant from turning on additional EDR modules for several days or weeks.

Finally, it is important to recognize that the economic value of the scenarios presented can only be really understood in relation to other costs and opportunities for savings. The likelihood that the water treatment manager will entertain the possibility of managing ecosystem services will depend on the returns from ecosystem services and how those returns are affected by other cost-saving opportunities or management decisions. The implication, once again, is that the decision-making and technological context of the ecosystem users are a critical determinant that will dictate whether or not resource users engage with ecosystem services in practice.

5. Conclusion

This paper has applied a deterministic model of biophysical processes to simulate alternative management options in the watershed. And yet the biophysical model alone could not have valued the ecosystem services related to stream temperature. Understanding the technological and decision making conditions downstream was essential because they dictated the terms under which valuation estimates could be made. This implies that different technologies or alternative management protocols would alter the value associated with ecosystem services that moderate stream temperature.

We have calculated a value for the ecosystem services by focusing on how these services could help treatment managers meet specific water quality targets. Focusing on how ecosystem services could contribute to meeting policy objectives helped target our research to specific ecosystem processes that were likely to create value. While many studies on ecosystem services seek to tabulate the multiple services provided by a landscape, quantifying more services is not more likely to capture the attention of a decision maker. In this case, we chose to document one service in detail because it was clear that this ecosystem process would assist resource managers in meeting specific water quality objectives. Focusing on how ecosystem processes contribute to meeting specific polity objectives has the added advantage of avoiding thorny questions concerning non-use valuation. In this case, the value associated with meeting water quality objectives is reported in clear and tangible use values because water managers told us, on their terms, how much savings would result from specific temperature reductions and reduced usage of EDR modules. Thus the results presented here only concern the use values for the water treatment facility and therefore offer a lower boundary estimate of the total value provided by riparian ecosystems.

Managing ecosystem services in order to meet specific objectives has several advantages. It simplifies the valuation process, engages decision makers, and facilitates the implementation of ideas about ecosystem services in practice. This approach may not be viable for all ecosystem services studied, especially when non-use values are dominant. However it does highlight that new opportunities to manage and restore ecosystem services may arise if we scrutinize the decision making context of those who depend on nature's services. By focusing on the end users, we will be more likely to harness the benefits that ecosystems provide.

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