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Is river rehabilitation economically viable in water-scarce basins?

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Abstract

Decisions on river rehabilitation actions are often based on cost-benefit analyses taking into account the costs and benefits of the considered management actions, but ecosystem services are often not included as benefits, despite recent evidences on the effects of river rehabilitations on ecosystem services. A cost-benefit analysis integrating market and non-market costs and benefits was undertaken in this study to assess the economic feasibility of a river rehabilitation project in a water scarce region, the Yarqon River Rehabilitation project (Israel). In this case, the costs included both the capital costs of implementing rehabilitation measures (including maintenance costs) and the opportunity costs of water allocation (foregone benefits to farmers from water provisioning for agriculture). The benefits of rehabilitation included the net marginal benefits of the cultural ecosystem services at local scale (estimated with a hedonic pricing method), and at regional scale (estimated with a value function transfer), in addition to the habitat service gene-pool protection (estimated with a replacement cost method). Bearing in mind the uncertainties surrounding water resource management decisions, especially in water scarce areas, a sensitivity and risk analysis were conducted using an analysis that included both Monte Carlo simulations and the standardized regression coefficients method. The rehabilitation of the Yarqon River provided positive net present values (approximately $139 million in 30-year period). This was thanks to the provision of cultural ecosystem services and despite the high rehabilitation costs, and that the massive water reallocation involved high foregone benefits to farmers. Therefore, these results highlight that river rehabilitation in water scarce regions can be economically viable due to the social amenity demand for urban rivers.

Key words: ecosystem services; cost-benefit analysis; river rehabilitation; sensitivity and risk analysis; water scarcity.

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1. Introduction

Currently, freshwater ecosystems are under threat from the effects of multiple anthropogenic stressors, including organic and inorganic pollution from point and non-point sources, geomorphological alterations, land use changes, water abstraction, invasive species, and pathogens (Vörösmarty et al., 2010). Because of these threats, the provision of many valuable goods and services from freshwater ecosystems are hampered (Dodds et al., 2013). To counteract the deleterious effects of these anthropogenic threats on freshwater ecosystems, water authorities develop management plans that include management actions such as river restorations to improve the ecological status of freshwater ecosystems (Bernhardt et al., 2005). In many cases, successful stream and river restorations have resulted in improved water quality, enhanced biodiversity, reduced flood risk, enhanced water purification capacity, or increased recreational opportunities (Wilson and Carpenter, 1999; Kenney et al., 2012; Martínez-Paz et al., 2014). Despite this fact, water authorities often rely on incomplete information when deciding among management actions on freshwater ecosystems. For example, the economic analysis of the costs and benefits of the alternative management actions do not normally include the monetary benefits associated with the provision of ecosystem services (Engel and Schaefer, 2013). Given this context, several monetary valuation methods have been developed to quantify the "instrumental value" of freshwater ecosystem services (Tallis and Lubchenco, 2014). In fact, several studies have quantified the changes in the monetary value of ecosystem services that are affected by the implementation of river rehabilitation projects (Choe et al., 1996; Bateman et al., 2006). Furthermore, some of these studies compared the monetary values of the multiple benefits with the rehabilitation costs (Loomis et al., 2000; Kenney et al., 2012), and some even performed a complete cost-benefit analysis (CBA) of river rehabilitation projects including ecosystem service estimates (Alam, 2008; Trenholm et al., 2013; Acuña et al., 2013). Overall, results from these studies have

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shown that freshwater ecosystems rehabilitation actions might be economically feasible if both market (e.g., water provisioning) and non-market (e.g., aesthetic information) benefits are considered.

In water scarce regions such as the Mediterranean region, water quantity and quality impacts are main drivers for ecological river degradation (González et al., 2012). In addition to an improvement in the sanitation services, frequently, ecologically successful river rehabilitation plans entail water allocation management decisions among different and competing users (e.g., environmental flows, water for irrigation, and water for urban supply), which might be a critical issue if water is scarce. In fact, many regions currently striving for economic and social development are challenged by increasingly related water problems such as availability of the resource (GWP, 2000). Besides, many of these countries foresee significant population growth and may experience a decrease in water availability due to climate change (Evans, 2009). The integration of ecosystem services into a cost-benefit analysis might help water authorities to properly evaluate rehabilitation plan's trade-offs and support the selection of the most socially optimal measures under water scarcity contexts (Engel and Schaefer, 2013). There are few studies assessing the costs and benefits of rehabilitation actions considering water allocation issues under water scarcity circumstances (Becker and Friedler, 2013; Halaburka et al., 2013; Becker et al., 2014; Chen et. al, 2015). Similarly to what previously stated, the inclusion of the non-marketed benefits have supposed a turning point that had significantly changed the results of the economic assessment towards favouring rehabilitation of rivers in scarce regions.

In line with these studies, we performed a cost-benefit analysis of the Yarqon River Rehabilitation Project (YRRP) in Israel, considering costs and benefits related with the provision of ecosystem services. We aimed to ascertain if urban river rehabilitation actions such as water reallocation from irrigation agriculture to environmental flows in water scarce regions provided positive or negative values. The issue is explored in the Israeli water policy

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context, where a significant disregard for the environmental quality of rivers at the expense of agricultural sector, is giving way to the use of alternative water sources and the rehabilitation of urban rivers for their ecological and amenity value (Gasith et al., 2010; Tal and Katz, 2012). With this aim in mind, we considered the rehabilitation trade-offs on both market and non-market benefit values, and both the capital costs of implementing rehabilitation measures (including maintenance costs) and the opportunity costs of water allocation (foregone benefits to farmers from water provisioning for agriculture).

2. Policy context: drivers of environmental degradation and rehabilitation of Israeli rivers

After the creation of the State of Israel in 1948, agriculture was conceived and promoted as the leading economic sector for nationalistic reasons (Menahem, 1998). At the same time, rapid population growth and industrial production contributed to the demand for water, increasing the competition among water sectors. This fast social and economic development caused many streams and rivers in Israel to quickly become polluted (Bar-Or, 2000; Hophmayer-Tokich, 2010). The point sources of pollution from municipal and industrial discharge, and the non-point sources of pollution from the use of pesticides and fertilizers, impacted deeply on the rivers' ecosystems (Gasith et al. 2010; Garcia and Pargament, 2014). This was exacerbated by the usage of poorly treated wastewater for irrigation, due to the increasing amount of wastewater production and the stabilizing demand of the agricultural sector, becoming an important non-point source of water pollution (Bar-Or 2000).

The political and social awareness regarding the environmental quality of rivers was negligible until the 1990s, when things started to change for several reasons. Firstly, during this time the country had to cope with a large immigration wave which increased urban development and the demand of urban open spaces and water use (Laster & Livney, 2012). Secondly, Israel's main

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economy drifted from agricultural into fast growing advanced market-economy. This caused that the main water consumer sector (agriculture) lost the political relevance it had enjoyed in the last decades (Hophmayer-Tokich, 2010). Besides, Israel’s severe water crisis occurred during the 1990s, reached its maximum at the beginning of 2000. Israel's water resource estimated capacity (1,800 Mm^3/year) was almost fully in use. The government promoted the construction of desalination plants under such pressure. Additionally, the government also boosted different actions to stimulate the increasing use of effluents for economical purposes, and to conserve and rehabilitate the water bodies. NGOs appeared as new actors at the beginning of the 1990’s, influencing decision-making through the legal systems and by raising public awareness (Hophmayer-Tokich, 2010). All these factors increased public awareness and the political pressure for conserving and rehabilitating rivers and other water resources in Israel, especially in urban areas. In this political context, in 1988, the Yarqon River Authority (YRA) was created, becoming the first river authority in Israel, dedicated to drainage works, rehabilitating the river and adapting it for leisure and recreational purposes (Garcia and Pargament, 2014).

3. Study site and rehabilitation project

The Yarqon River is situated in the centre of Israel and flows through the most densely populated area of the country (Figure 1). The river’s main stem is approximately 28 km in length, and the size of its watershed is about 1800 km^2, having almost two-thirds of the river basin located in the West Bank (Palestine). In the 1950s, the Yarqon-Negev pipeline was constructed to supply industrial and domestic demand and agricultural settlements in the southern region of the Negev. Before the construction of the pipeline, 7 m^3/s of water flowed permanently into the river from the springs located at Rosh Ha’ayin, maintained by the large Yarqon-Taninim karst aquifer (Avisar et al., 2006). However, the installation of the pipeline diverted the springs’ flow, causing a drop in the water table and almost stopping the natural

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flow of water. An additional stressor was the discharge of poorly treated water from the wastewater treatment plants (WWTPs). Health and aesthetic nuisances, such as mosquito breeding and fish-kills, were common during this period before the rehabilitation (Gasith and Pargament, 1998).

[FIG 1 ABOUT HERE]

In order to improve the ecological status of the Yarqon River, the YRRP was approved in 2003 (Garcia and Pargament, 2014). The YRRP included the following components: 1) increasing water quantity in the river by reevaluating water allocation, 2) increasing water quality by improving wastewater treatment, and 3) cleaning the river channel and rehabilitating its biodiversity (flora and fauna) and aesthetic and recreational values. Regarding the first point, the water allowed to flow downstream from the springs increased initially from 0.05 m^3/s to 0.16 m^3/s (2011) and later to 0.23 m^3/s (2012). Regarding the second point, the YRRP included upgrades to the Kfar Saba-Hod Hasharon WWTP (2009) and the Ramat Hasharon WWTP (2011), thereby improving the water quality of the effluent from these plants to a tertiary level. Furthermore, the YRRP also included the construction of wetlands to further treat the Kfar Saba-Hod Hasharon effluent before discharging it into the river. The addition of the wetlands improved the effluent quality, as well as leveled out the pollution fluctuations. Overall, WWTPs discharge 0.36 m^3/s (0.08 m^3/s from the Ramat Hasharon WWTP, and the rest from the constructed wetland) of water to the Yarqon River at two different points (Figure 1), and are, therefore, the main surface water sources in the basin. Thanks to these actions, the median annual flow of the river has increased from 0.13 – 0.54 Mm^3/year before the YRRP to currently 9 – 18 Mm^3/year, and the discharged water from WWTP complies with the Public Health Regulations of 2010 (Effluent Quality Standards and Waste Water Treatment Rules) (IMEP 2010). With regard to the third point, the YRRP included the partial rehabilitation of the riparian and aquatic habitats in order to support rehabilitation of biodiversity. The enhancement

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of supporting ecological services allowed for the successful reintroduction of the endemic *Acanthobrama telavivensis* fish, which was catalogued as “extinct in the wild” by the IUCN Red List of Threatened Species in 2000 (Crivelli, 2006), but currently can be found in many reaches within the Yarqon Basin (Goren, 2009).

4. Material and methods

4.1. Monetary valuation and cost-benefit analysis

The Economics of Ecosystems and Biodiversity framework (TEEB, 2010) framework explicitly distinguishes between services (contribution to human welfare) and benefits (welfare gains the services generate) (Boyd and Banzhaf, 2007) and considers that services can benefit society directly and indirectly (Fisher et al., 2008). In order to screen which of the TEEB set of ecosystem services will represent a significant beneficial impact (in terms of magnitude or likely to occur frequently), we reviewed relevant scientific papers about ecosystems services in urban rivers, the available context-specific information regarding the YRRP, and consulted some policy-makers and stakeholders involved in the project (Kandulu et al., 2014). On the basis of this information, aesthetic information, opportunities for recreation, and gene-pool protection, were the 3 ecosystem services selected for quantitative assessment. Figure 2 shows the linkages between the previously described rehabilitation actions of the YRRP, the biophysical structures and processes of the Yarqon River ecosystem, the ecosystem services, and the benefits and values according to TEEB (2010). These ecosystem services generate benefits (more pleasant living conditions, recreational enjoyment and maintaining the vitality of the gene-pool) that could be quantifiable in monetary terms.

[FIG 2 ABOUT HERE]

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Cost-benefit analysis is a rational and systematic approach used in public or private decision-making to evaluate whether the (economic, environmental and social) benefits of an action outweigh the costs. A project should thus be supported if the benefits for the gainers are sufficiently greater than the costs for the losers, so they could - in principle - compensate the losers and still be better off (Pearce et al., 2006). In this study, the performed cost-benefit analysis considered the capital costs associated with implementation of the different rehabilitation actions, the maintenance costs of these actions, and the foregone benefits to farmers. The later is produced by the reduction in the water allocation to agriculture resulting from the increase in the amount of water allowed to flow downstream from the springs and the WWTPs, considering that in Central Israel the reclaimed water would be used for irrigation. The initial year of the CBA was 2003 because it was the first year costs were incurred related to consultancy, design and management. Marginal benefits included the improved aesthetic value of the river, new opportunities for recreation, and the increase in protection level for one endangered fish species. The annual benefits were estimated based on the water quality improvement in the river and then summed for a period after the rehabilitation actions took effect (from 2012 onward), as explained in more detail bellow. Both costs and benefits were estimated as net present values (NPV) for different time-periods (10 and 30 years starting from 2003) applying a discount rate of 4 % and expressing results in 2003 US$. We chose these two time-periods and discount rate in this analysis because they are commonly used in CBA of environmental projects in water bodies (Van Beukering et al., 2003; Alam 2008; Becker et al., 2014). However, the 30-year period (2003-2033) was used as a reference when discussing the present values of costs and benefits separately and in conducting the sensitivity analysis. The return-on-investment (ROI) was calculated as the ratio of the NPV of benefits and the NPV of costs, and was used as an indicator of the economic viability of the rehabilitation project.

4.2. Cost estimates

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4.2.1. Capital rehabilitation costs

The capital cost components (see Table A.1 in the appendix A.1) were those related with the WWTPs upgrading to improve the quality of the discharged water ($32.69 million - 71.1 % of the total), the wetland construction ($10.28 million - 22.4 %), and the riparian zone restoration (channel cleaning, ecological development programs, pollution prevention, among others) ($2.99 million - 6.5 %). These costs were incurred from the year these actions were initiated, 2004, to 2013 (see Table A.1).

4.2.2. Operation and maintenance costs

The operation and maintenance costs (Table A.1) were incurred by the Yarqon River Authority from 2003 for water reallocation, pollution prevention, consulting, manpower, and monitoring, and by Mekorot (Israel's National Water Company) as a result of upgrades to the WWTPs.

4.2.3. Opportunity costs of water allocation

Under conditions of water scarcity, any decision regarding water reallocation between users might involve important opportunity costs (Vaux, 2012), understanding this as "*the value of goods in terms of a lost alternative use of those goods*" (Hernández et al., 2006). For example, not considering the social opportunity costs derived from agricultural irrigation with reclaimed water if this water is reallocated for another purpose (e.g. stream flow augmentation), might lead to the underestimation of the total costs of a project. This is particularly relevant under conditions of scarcity, where reusing the water resource has become a common practice (Lazarova et al., 2001). Israel and the Yarqon Basin are characterized by scarce water resources which limit agricultural production potential (Haruvy, 1998). All water resources reallocated to the river (WWTP effluents and spring water) comply with the quality standards to be used for agricultural irrigation (IMEP, 2010). Therefore, the opportunity costs of water

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allocation to environmental flows (Table A.1) are considered as the foregone net revenues from taking water out of agricultural production. These are derived from agricultural irrigation with reclaimed water, that is, the specific net benefit (value added to crops), based on a production function-based approach in Central Israel (lower limits and base-case for the sensitivity analysis) (Haruvy, 1998, 2009). Also, as an upper limit estimation for the sensitivity analysis, we considered the cost of production of desalinated water, since is the only alternative source of water available in the region (Helbetz, personal communication). Table 1 shows the values (base-case and upper/lower limits) used to estimate opportunity costs.

4.3. Cultural ecosystem service benefit estimates

In this study we followed the approach of considering that both cultural ecosystem services (aesthetic information and opportunities for recreation) contribute complementary to obtain the derived benefits as a bundle (Plieninger et al., 2013). Previous studies in the river rehabilitation literature concluded that aesthetically pleasant landscapes attract recreationists (Asakawa et al., 2004). Similarly, facilitating the recreational use might improve aesthetic perception towards a rehabilitated river (Junker and Buchecker, 2008). These facts prove the certainty of considering both ecosystem services as a bundle of cultural services contributing complementarily to well-being. In this context, these two ecosystem services were estimated at local (or neighborhood) and regional scale using hedonic pricing method and travel cost value function transfer method correspondingly. The main reason for that was to integrate the various spatial dimensions implied while estimating the cultural services benefits (Hein et al., 2006). Concretely, if hedonic pricing method derived benefits were those only included, that option would not consider the benefits obtained at larger scale reflected in the presence of visitors from nearby towns. Contrarily, considering only the travel cost value estimation would disregard the benefits provided to those who have a house nearby and would not have additional travel cost expenses to visit the Yarqon. Therefore, since both revealed preference methods have been applied to estimate values for different affected stakeholders at different scales (Hein et al., 2006), complementarity in their use is proven and that rejects the occurrence of double counting (Champ et al., 2012).

4.3.1. Local benefit estimates: hedonic pricing method

The marginal benefit derived from the cultural ecosystem service at local scale was estimated from the increase in housing rent prices caused by the water quality improvement due to the river rehabilitation, comparing it with the previous water quality situation before the rehabilitation. This was conducted using the hedonic pricing method as described in Freeman (1993), which, based on variations in housing prices, is commonly used to estimate the economic effects of marginal changes in water quality in aquatic ecosystems (Gibbs et al., 2002; Poor et al., 2007).

A sample of 826 properties in the study area was collected for the period from March to June 2013 in the Tel Aviv Metropolitan Area (mostly in the city of Tel Aviv where residential areas are located closest to the Yarqon). The sources of data were various real estate websites with advertised asking prices and information on home attributes. 8% of the average price was subtracted to address the negotiation difference between asking price and transaction price of houses in Israel (Eshet et al., 2007). Since we did not have access to data from a period of time before the rehabilitation we used a cross-sectional approach (spatially distributed data collected from a sample of houses, at one specific point in time) to estimate the impact of water quality change in the housing price. More concretely, we first estimated the current effect of the water quality gradient along the river on the housing price using this sample and applying a hedonic pricing model. Then we interpolated this effect on the housing price previous to the rehabilitation works, based on river water quality data from the past. Table A.2 (in the appendix A.1) shows the characteristics of the houses that were used in this analysis as

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additional explanatory variables in order to get a more accurate response estimation of the water quality improvement parameter, as well as some descriptive statistics on the gathered data. The price of houses (variable *price* in Table A.2) was converted to annual rental price (*rent* in US$/month) with the purpose of computing the results of the hedonic pricing model into a stream of households' value per year for improving the water quality in the river (Siderelis and Perrygo, 1996). Further details on the conversion from average sale price to rent price of the houses can be found in the supporting information (appendix A.2, section A.2.1).

Housing rent pricing was then related to the water quality index (WQI) defined in (McClelland 1974) which is a standardized method for comparing the water quality of various bodies. WQI has recently been tested and found to be positively and significantly related to WTP for water quality improvement in an extensive meta-analysis of valuation studies in water bodies (Ge et al. 2013). The WQI was calculated from averaging concentrations of 8 quality parameters at 4 sampling points in the Yarqon for the time periods 2000-2008 (before the rehabilitation) and 2009-2012 (after the rehabilitation), and 10 to 25 samples along these periods in each sampling point. In order to get a WQI value along the river every 5 meters, an interpolation from the 4 sampling points was applied. Then, each of the 826 properties was matched to the closest point to the river, assigning for each house (with its corresponding rental price) a WQI value. Detailed information on the procedure to estimate the WQI can be found in the supporting information (appendix A.2, section A.2.2). Finally, a multi-variate linear regression was conducted between rental price of the houses (dependent variable in the regression) and the several explanatory variables related to house characteristics, neighborhood attributes and environmental criteria (see Table A.2) using the mixed log-level functional form (Troy and Groven 2008). The results of the regression model (Table A.3 in the appendix A.1) show that by increasing one unit of the WQI (*DWQImodel* variable in the hedonic pricing model) an increase of 0.354 % of the rent price of the houses is observed. This value was then used for

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the estimation of the benefits in the base case scenario. The 95% confidence internal values (0.143% - 0.565%) were used in the sensitivity and risk analysis as lower and upper limits for *DWQImodel* parameter (Table 1).

To calculate the local benefits of cultural ecosystem service, we chose the study area to be 28 km long and 1 km wide, centered along the midline of the river (500 m on each side from the center of the river); this width is the most commonly reported in the literature applying hedonic pricing model results in rivers (Halaburka et al., 2013). According to a land use GIS layer, within the study area there are approximately 2.341.000 m^2 pertaining to residential area. Using a parameter of housing density in the base-case scenario of 0.00743 houses/m^2 (CBSI, 2011), (0.00418-0.00750 for the lower and upper limit values in the sensitivity analysis), it is estimated that the study area enclosed approximately 17.400 houses. The estimated aesthetic benefits for the base case scenario are shown in Table A.4 (in the appendix A.1). According to these results, households closest to the Yarqon River (within 1 km) have an average monthly value per person of $66.49 for an increase of 10.20 WQI units, the level achieved through the rehabilitation process. This represented a total annual benefit of approximately $14 million per year.

4.3.2. Regional benefit estimates: value function transfer method

The change in cultural ecosystem services at regional scale in monetary value after rehabilitation of the river was quantified here. Since limited data were available for the Yarqon River, we used a benefit transfer method, particularly the value function transfer variant (Lovett et al., 1997). This method is based on adapting the monetary values of ecosystem services estimated for the location where the original study was conducted (study site) to a new location (policy site). The value function transfer is the most accurate benefit transfer method, as long as basic information on both the policy site and the study site is available (Loomis,

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1992; Lovett et al., 1997; Johnston and Rosenberger, 2010), as was the case here. For instance, Loomis (1992) tested a travel cost value function transfer estimation with 10 travel cost original studies in Oregon (USA) various steelhead rivers, finding that the percentage of error ranged from 5 to 15% only. The study site used was the Alexander-Zeimar River (approximately 35 km north of the Yarqon and with very similar geomorphologic and climatologic characteristics, e.g. median annual flow of 15–20 Mm^3/year near its mouth). Becker and Friedler (2013) carried out a study to estimate the benefits of a rehabilitation plan, employing a contingent behavior travel cost demand model. In the case of the Alexander-Zeimar River, Becker and Friedler surveyed visitors of the river about their past (before the river rehabilitation) and present visitation rates. This information was later used to estimate the recreation and tourism monetary value. In order to carry out the value function transfer method in the Yarqon, we used the travel cost model's estimated coefficients obtained in Becker and Friedler (2013) with socio-economic information obtained at the Yarqon Basin to compute visitation rates (before and after the rehabilitation) and then the individual consumer surplus. With this later benefits estimation per household and data on annual number of visitors to the Yarqon, we obtained the marginal benefit derived from the cultural ecosystem services at regional scale caused by the rehabilitation of the Yarqon. Table A.5 (in the appendix A.1) describes the function variables and coefficients obtained by Becker and Friedler (2013) and used in this case. A detailed explanation on the following methodological steps to apply the value function transfer can be found in the appendix A.2 (section A.2.3).

The individual consumer surplus was calculated by 1) dividing the rehabilitation coefficient by the cost coefficient (*Water quality* and *Travel cost* variables, respectively, presented in the Table A.5) or 2) dividing the difference between the estimated number of visits per household before and after the river rehabilitation (weighted average household size of 2.86 in the sampled localities) by the *Travel cost* coefficient (Becker and Friedler 2013). The results of the

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recreation and tourism valuations, using the two methods explained above, showed that individual consumer surplus was 167.89 and 213.99 New Israeli Shekel (NIS) per person (or $15.65 and $19.95 per household), respectively for an 11.67 unit increase in the WQI. In Becker and Friedler (2013) case study, the resulting household consumer surplus was $65.25 and $66.75 for the two methods. Because the municipalities surrounding the Yarqon are far more densely populated compared to those surrounding the Alexander-Zeimar, it is logical that average visitor comes from closer locations and thus it holds an expected lower consumer surplus. Multiplying the average of these two values ($17.80) by the annual number of visitors (980.000 households (or 2.80 million people) according to the park authority in the Yarqon) gives an annual total consumer surplus of approximately $17 million.

4.4. Gene-pool protection benefit estimates

This service focuses on the reintroduction of the endangered *Acanthobrama telavivensis* fish which was possible after the rehabilitation project. The replacement cost (RC) method was used (Gren et al., 1994) by estimating the cost of the breeding center created to rescue the endangered fish. The breeding center, located in the Ichthyological Laboratory at Tel Aviv University, received initially 150 fish. During the first year (October 2000), the fish population grew to approximately 700. After the second year (October 2001), the fish population grew to approximately 10,000, reaching full capacity of the breeding facilities (Goren, 2009). In 2006 the fish was reintroduced to several rehabilitated sites and artificial ponds within the Yarqon Basin. From 2007 to 2013, their population was monitored and results revealed large populations of various sizes and ages. As mentioned earlier, the YRRP enhanced the supporting ecological services allowing for the successful reintroduction of *Acanthobrama telavivensis* fish (Goren, 2009; Goren, 2014). Therefore, the investments in the breeding facilities assured the existence of a healthy population and the viability of following

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reintroduction actions. This practice of valuing this habitat service by measuring the cost of fish breeding and stocking programs has been previously exemplified (EC, 2012).

Information on the capital costs (e.g., tanks, pumps), and operational and maintenance costs (e.g., food, electricity, stuff) gave us a price-based low-bound estimate of the benefits (replacement cost) of protecting fish species. Assuming an average lifetime of 10 years for the breeding facilities (Pargament, personal communication), it is estimated that a total annual cost of $22,987 was avoided as a result of the rehabilitation project.

4.5. Sensitivity and risk analysis

Sensitivity analysis can be performed to identify the most critical parameters for the estimation of the costs and benefits, and risk analysis can be subsequently performed to explore the stability and the resilience of the estimated costs and benefits to changes in the most significant parameters of the system (Corominas and Neumann, 2014). In this study, the sensitivity analysis evaluated the change in the NPV due to changes in the parameters of the cost-benefit analysis. A multiple regression analysis with standardized regression coefficients (SRC) was carried out to explore the sensitivity of NPV to the input parameters. SRCs were estimated as presented in eq. 1, where b_i are the un-standardized regression coefficients, σ_{X_i} are the standard deviations of the parameters, and σ_Y is the standard deviation of the output.

$$\beta_i = b_i \cdot \frac{\sigma_{X_i}}{\sigma_Y} \qquad \text{(eq.1)}$$

Details of the costs and benefits derived equations as explained in the previous sections, and used in these analysis, can be found in can be found in the appendix A.2 (section A.2.4). Table 1 shows the lower-limit and upper-limit values of the 18 input parameters, which present a range of values reflecting the different sources of information and are therefore a potential

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source of uncertainty. Three of these 18 parameters were considered to calculate the costs (see Table A.1), and the remaining 15 were used to estimate the benefits. The selection of the parameters to be included in the analysis was primarily limited to the availability of a range of values (lower and upper limits) from different information sources. Using Matlab, Monte Carlo simulations (2000 in total) were performed using uniform distributions to obtain stable estimates of the SRC. According to the method, those parameters with larger SRCs are more sensitive to the NPV estimate (Saltelli et al., 2000). To test the relative importance of the parameters, β_i was estimated, which corresponds to first-order variance contribution of the input parameters X_i to the output Y.

5. Results

5.1. Costs and benefits from the YRRP

The NPV of the cost of the YRRP for the period 2003-2033 equals approximately $191 million. The highest cost component of the YRRP was the foregone benefits to farmers, with a NPV of approximately $108 million (56.3 % of the total). The implementation of the rehabilitation activities was the second highest cost, at $36 million (18.8 %). The annual Yarqon River Authority expenses and the additional water treatment operational and maintenance costs associated with the upgrades to the WWTPs contributed similarly to the total costs, with a NPV of $26 (13.6 %) and $21 (11.2 %) million, respectively.

In total, the benefits of the rehabilitation of the Yarqon River provided approximately $14.60/year per person, or $31 million per year. The analysis is considered regional in scale, although some benefits accrued nationally (e.g., gene-pool protection) because the target population was the same for all benefit estimates (i.e., the population used to quantify the ecosystem service recreation and tourism pertaining to the municipalities within 15 km distance to the Yarqon, with a total population of 2,138,737 inhabitants). The ecosystem

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service that is estimated to produce the most benefit in the period 2003-2033 is regional cultural ecosystem services, with a NPV of $183 million, or 55.51% of the total benefits. The second largest contributor to total benefits is local cultural ecosystem services ($145 million, 44.42%). Finally, the total present value of gene-pool protection was $242,726 (0.074%).

5.2. Cost-benefit analysis

Figure 3 shows the results of the CBA and the sum of the NPV for the considered time-periods (2003 – 2013 and 2003 – 2033). According to the results for 2003 – 2013, the NPV of the Yarqon River rehabilitation project was approximately -$29 million, with a ROI of -0.41. The ROI becomes greater than 0 in the period 2003 – 2016. For 2003 – 2033, the NPV of the YRRP was approximately $139 million, with a ROI of 0.73. The distributional analysis of the costs and benefits helps identify winners and losers, by providing detailed information about which stakeholders have benefited (or been disadvantaged) from the YRRP implementation.

[FIG. 3 ABOUT HERE]

5.3. Sensitivity and risk analysis

Considering the uncertainty associated with the range of values of the different input parameters included in the Monte Carlo simulations, it was found that the likelihood of obtaining a positive NPV for the reference period 2003-2033 was 90.8 %. The simulated median NPV was $104 million, the 25th percentile was $51 million, and the 75th percentile was $164 million.

Estimation of the SRC enables identification of the input parameters that influence NPV results the most (Table 1). Values of $R^2 > 0.7$ in a regression model suggest that the relationships present enough linearity to be used to assess sensitivities (Saltelli et al., 2005). The R^2 in this case was 0.94, and thus the linearity assumption was satisfied. The three parameters with a

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high value of β in the NPV models were: 1) the net benefit of the treated effluent for irrigation (*Btef*), which was used to estimate the foregone benefits to farmers, with a β of -0.54; 2) the parameter that predicts the effect of the change in WQI on housing rental prices, which was used to estimate the cultural services benefits (parameter *DWQImodel* in Table A.3), with an β of 0.48 for the NPV; and 3) the total number of visits per year to the Yarqon (*NVY*), which was used to calculate the annual total consumer surplus associated with cultural ecosystem services, with a β of 0.41. Only the β of *Btef* was negative, indicating that an increase in the value of this parameter would cause a decrease in the NPV. The β of the other 2 parameters were positive, indicating that an increase in their value would also increase the NPV.

[TABLE 1 ABOUT HERE]

6. Discussion

Despite the multiple costs associated with the YRRP, including costs of implementation and maintenance as well as foregone benefits to farmers, the benefits surpassed costs, therefore showing that the YRRP was a successful rehabilitation project with a marginal value of approximately $139 million (NPV 2003-2033). Cultural ecosystem services were those contributing the most to the human wellbeing. The ecosystem services per person resulted in $14.60/year ($41.76/year per household), which is in the order of magnitude of values obtained in previous studies which estimated ecosystem services related to the rehabilitation of river ecosystems using willingness-to-pay (WTP). In Davao (Philippines), a WTP of $21.12/year per household was estimated for an improvement in water quality of the rivers and sea near their community (Choe et al., 1996). In the Buriganga River (Bangladesh), Alam (2008) found that the WTP for a complete urban river restoration program was $17.16/year per household. In the case of the Tame River, which passes through the city of Birmingham (UK), the WTP was estimated to range from $12.69 - 38.88/year per household, depending on the water quality

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improvement scheme (small-large) and the valuation method (Bateman et al. 2006). In the Odense River in Denmark, the WTP to restore the river to a healthy ecological status ranged from \$36.40 to 79.42/year per household, depending on the model specifications and whether the individual was a non-user or a user of the river (Jørgensen et al., 2013). Finally, in the urban river rehabilitation of the River Segura (Spain), this value ranged from \$10.03 - 26.67/year per household for non-users and users, respectively (Martínez-Paz et al., 2014). The overall comparison with previous studies shows that the ecosystem services value per person in the Yarqon Basin are 27.45% higher on average.

The Monte Carlo simulation results indicate that there is a 90.8 % probability of obtaining a positive NPV or ROI higher than 0, confirming the positive impact of the YRRP implementation on human wellbeing. The analysis of the SRC revealed that the most relevant input variable was the net benefit of the treated effluent for irrigation (*Btef*). This result demonstrates the importance of considering the opportunity costs of water allocation when conducting CBA under conditions of water scarcity. In the worst-case scenario in which the only substitute source of water for irrigation is desalinated water, with an estimated upper-bound price used in the sensitivity analysis of approximately \$0.99/m^3 (based on the marginal price provided by Eng. Ilan Helbetz (personal communication) (Table 1), the YRRP might be economically unfeasible. For that reason, implementing water demand management actions or water reuse technologies that ensure an efficient water provision price for certain purposes might strongly determine the affordability of environmental rehabilitations of rivers in scarce regions (Chen et al., 2015). The second most important parameter in terms of variance in the NPV regression model was the coefficient *DWQImodel*, which predicts the impact of WQI on housing rental price and was obtained from the hedonic pricing model. This shows the importance of the river's water quality for aesthetic, recreational or other cultural values gained by city-dwellers living in close proximity to the river (Poor et al., 2007). In a hypothetical

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scenario where city-dwellers barely appreciated the value of having a “clean” Yarqon, the CBA would have likely yielded negative results. Similarly, total number of visits per year to the Yarqon (*NVY*) was also identified as a relevant input variable that indirectly influences the NPV through the valuation of recreation and tourism. Even though it might be at odds with ecological purposes of rehabilitation, the recreational facilities and opportunities of the rehabilitated Yarqon might significantly determine the sustainability of the project.

As was once the case of the Yarqon, many river in water scare regions are degraded because of a predominant socio-political and economical paradigm not aligned with the principles of sustainability in water resource management (Bar-Or, 2000; Hophmayer-Tokich, 2010). In Israel, this paradigm has changed over the last years, and that has encouraged policy-makers to implement river rehabilitation initiatives to improve the environmental quality in these water resources (Laster & Livney, 2012; Garcia and Pargament, 2014). In this case, the rehabilitation of the Yarqon has improved considerably the ecological and amenity values of this river but it has also involved a major economic investment and water resources reallocation. Based on the results presented in this study, it can be concluded that, especially in urban areas, rehabilitating the environmental quality of rivers produce a greater impact on human well-being. Therefore, investing in rehabilitation actions and reallocating water resources to environmental flows becomes a feasible policy decision even in water scarce regions mainly due to the social amenity demand for urban rivers (Tal and Katz, 2012).

6.1. Limitations of the study

We are aware of the simplicity of our approach in estimating the change in ecosystem services caused by the implementation of the YRRP. Numerous methods could have been used to estimate the effects of the rehabilitation on human well-being, but we suggest that ours is a reasonable approach that uses realistic costs and benefits. We think that the major weaknesses

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in our study include the following: (i) the use of a benefit transfer method rather than original research to value the cultural service at regional scale; (ii) the use of advertised prices rather than real transaction values in the hedonic pricing model; and (iii) the used methodology to assess changes in the water quality. In regards to the use of a benefit transfer method, we believe that although the value estimated for the policy site was adjusted based on a value function, this might still represent a relevant source of uncertainty (Loomis, 1992). The sensitivity analysis, as explained above, enabled a test of whether the main source of variability in the calculation of NPV was derived from the application of the value function transfer method. In regards to the use of advertised prices, some authors claim that when conducting this type of analysis, actual sale prices should be used rather than other types of prices because sale prices reflect the equilibrium market price (Mahan et al., 2000). However, some other authors supported the use of appraised market prices and argued that these prices avoided the bias that might occur during normal market activity (Siderelis and Perrygo, 1996). In fact, using actual sale prices was set as priority while planning the methodology. Nevertheless, in some countries like Israel, obtaining the information of the transaction price is extremely difficult (Eshet et al., 2007). This methodological obstacle justified the use of the sensitivity analysis with a range of values for the parameter of the negotiation difference between asking price and transaction price of houses in Israel (*ARPratio* in Table 1). The sensitivity analysis proved that the influence on the NPV results for this parameter is insignificant (β = -0.012). Finally, in regards to the methodology used to assess water quality, there is no consensus among researchers regarding the most reliable water quality index to use for this purpose. Bateman et al. (2006) applied the Resources for the Future (RFF) water quality index. Van Houtven et al. (2007) constructed a 10-point water quality index (WQI10) based on Vaughan's (1986) RFF and the National Sanitation Foundation water quality index (WQI) (McClelland 1974). Despite the time lasted since its publication (ca 40 years), WQI is a robust approach based on a wide survey to more than 90 experts in water quality management from all over the

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USA. Beside, this approach has recently been tested and found to be positively and significantly related to WTP for water quality improvement in an extensive meta-analysis of valuation studies in water bodies (Ge et al., 2013). Future research on ecosystem services valuation in aquatic ecosystems should develop customized water quality indexes that serve as a bio-physical indicator of the provision of specific ecosystem services such as aesthetic information or recreational opportunities.

7. Conclusions

The rehabilitation measures conducted for the Yarqon River have been very beneficial for the society as a whole, as non-marketed benefits surpassed the considered costs. These results are especially relevant because positive NPV were obtained despite the massive water reallocation involved in the rehabilitation, which resulted in high foregone benefits to farmers. Moreover, this study has highlighted the need to implement comprehensive sensitivity and risk analysis due to the uncertainty concerning the economic assessment of rehabilitation plans. The sensitivity analysis shows that the net benefit of the treated effluent for irrigation, which was applied to estimate the foregone benefits to farmers, had the largest influence on the results of the CBA. This finding demonstrated the relevance of considering the social opportunity costs derived from the foregone benefits from other ecosystem services in river rehabilitations under similar conditions of water scarcity. The sensitivity analysis also demonstrates the relevance of non-marketed cultural ecosystem services parameters to contribute to the benefits. The risk analysis shows that the likelihood of obtaining a positive NPV is very high (91 %). Therefore, this study demonstrates that even under conditions of water scarcity, rehabilitation of aquatic ecosystems might be not only affordable, but a highly valuable management action, even if river water reallocation (freshwater and reclaimed water) is required. Consequently, it is recommended that water resource and environmental decision-makers in water scarce regions, support conserving and rehabilitating aquatic ecosystems, which have been proven to be

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relevant ecological assets to help sustain human well-being, while enhancing the cultural ecosystem services and efficient water reuse for different purposes.

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Appendices

Additional supporting information may be found in the online version of this article.

Appendix A.1. Supplementary tables

Appendix A.2. Extended methods

Figure A.1. Map of the accumulated travel time to get to the Yarqon.

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Table legends

Table 1. Information about the input parameters, range of values, and standardized regression coefficients for NPV and ROI.

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Table 1.

Element	Variables	Unit	Base case (lower – upper limit)	Reference	β (NPV)
Aesthetic information	*PRentInter*: Constant of the price/rent model (see table A.6)	-	299.777 (281.489- 318.065)	95 % Conf. Interval of the regression intercept	0.001
	PRentCoef: Coefficient of the price/rent model (see table A.6)	-	0.001979 (0.001935 - 0.002022)	95 % Conf. Interval of the regression coefficient	0.018
	HD: Housing density in the study area	Houses/m^2	0.00743 (0.00418-0.00750)	CBSI (2011)	0.225
	ARPratio: Asking/real housing price ratio	-	0.08 (0.06-0.10)	Eshet et al. (2007)	-0.012
	DWQI: Average of the difference in the closest WQI of the sample of houses (within 500 m to the Yarqon).	WQI units	10.2 (6.49-13.91)	95 % Conf. Interval	0.294
	DWQImodel: Coefficient (*WQI*) that predicts the impact of WQI on the rent price (see table A.3)	-	0.00354 (0.00143 -0.00565)	95 % Conf. Interval of the parameter result	0.483
Recreation and tourism	*Incpar*: Income parameter from the sample of municipalities (see table A.5)	-	2.940 (2.225-3.655)	95 % Conf. Interval	0.011
	Childpar: Children parameter from the sample of municipalities (see table A.5)	-	0.680 (0.648-0.712)	95 % Conf. Interval	0.007
	LT: Leisure time in times the travel time estimated to the Yarqon	-	7.5 (5- 10)	YRA (personal communication)	-0.001
	Lcost: Leisure cost calculated from the accumulated time cost map	Israeli new shekel (NIS)	0.382 (0.382-0.502)	(Shiftan and Albert, 2012, Gitelman et al., 2011)	0.007
	BefWQIriv: Water quality index for the whole river in the period 2000/2008	WQI units	47.518 (45.929-49.106)	95 % Conf. Interval	-0.198
	AftWQIriv: Water quality index for the whole river in the period 2009/2012	WQI units	59.192 (57.930-61.716)	95 % Conf. Interval	0.233
	NVY: Total number of visits per year to the Yarqon	Visits/year	2,800,000 (2,052,500-3,700,000)	Ganei Yehoshua Park Authority (personal communication), KIVUN (unpublished)	0.407
	Hsize: Household size	-	2.875 (2.822-2.928)	95 % Conf. Interval	-0.049
Costs (see table A.1)	*Yexp*: Uncertainty factor based on last 5 years.	$Thousand	0 (-232.08-232.08)	95 % Conf. Interval	-0.005
	AdOM: Additional treatment costs due to the WWTPs upgrading	$/m^3	0.136 (0.05-0.17)	Helbetz (personal communication), Lavee (2011), Rejwan (2011)	-0.069
	Btef: Marginal net benefit of the treated effluent for irrigation	$/m^3	0.521 (0.25-0.99)	Haruvy (1998), Haruvy et al. (2009), Helbetz (personal communication)	-0.540
Discount rate	*i*: Discount rate	-	0.04 (0.03-0.05)	EC (2008)	-0.174

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Figure legends

Figure 1. Location of the Yarqon River.

Figure 2. Pathways from biophysical structures and processes to human well-being for the effects of the YRRP implementation in the Yarqon River (Israel).

Figure 3. Sum of the present values of the ecosystem services benefits and costs elements along time periods 2003 – 2013 and 2003 – 2033.

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Figures

Figure 1.

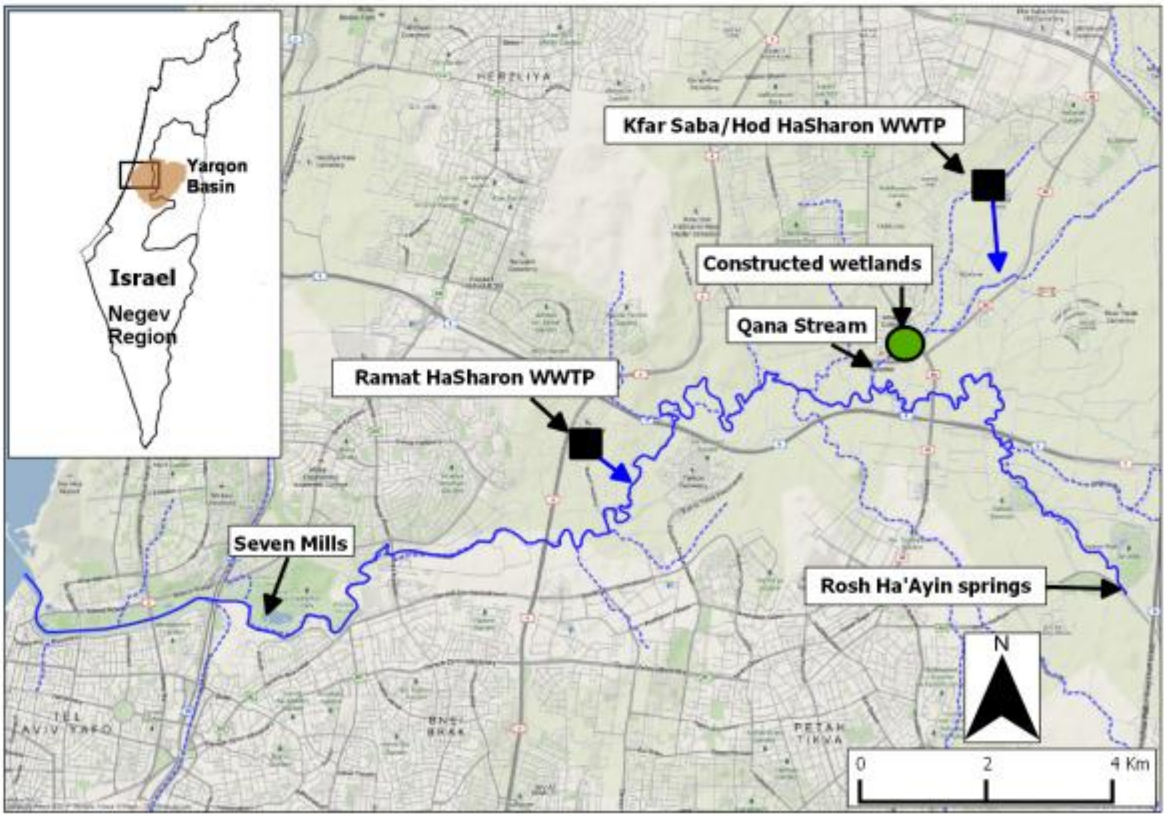

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Figure 2.

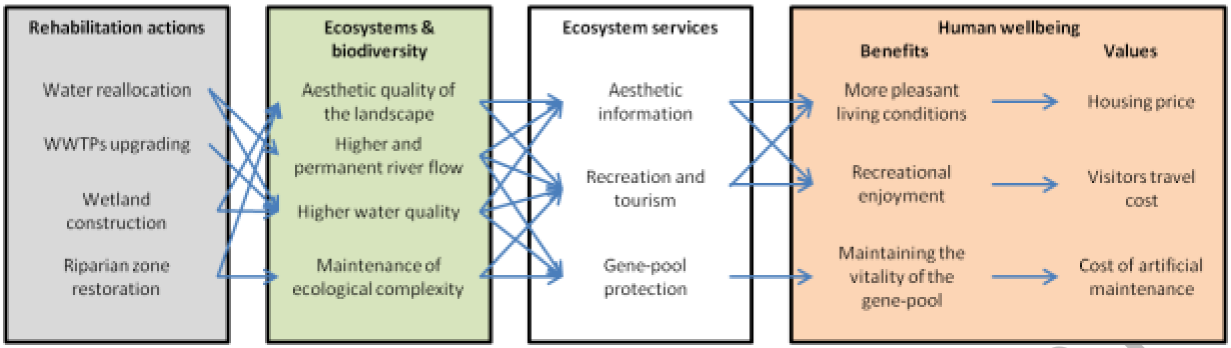

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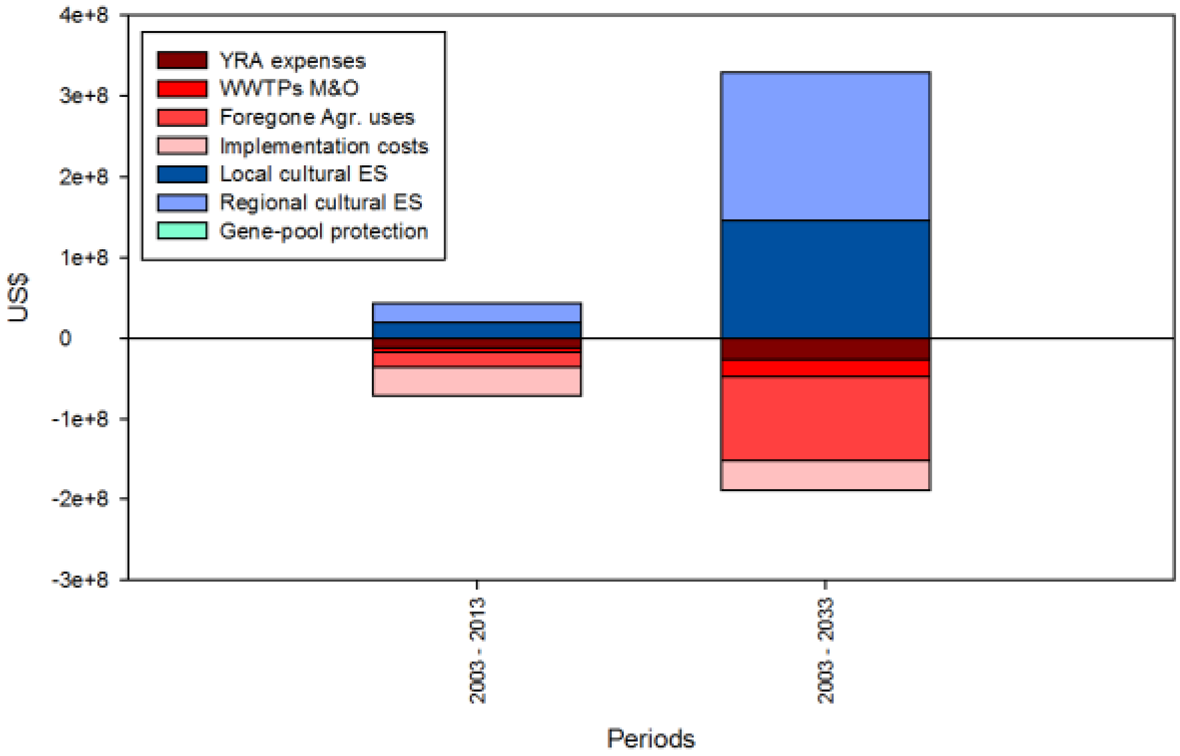
Figure 3.



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