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Ecological Economics 58 (2006) 606–616

ECOLOGICAL ECONOMICS

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ANALYSIS

Forests and water: The value of native temperate forests in supplying water for human consumption

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Received 12 January 2005; received in revised form 20 August 2005; accepted 21 August 2005
Available online 26 September 2005

Abstract

Temperate forests in the Southern Hemisphere provide ecosystem services of local and global importance such as internal nutrient cycling, soil protection, biodiversity conservation, climate regulation, and water supply. Under a scenario of global climatic change, water supply represents one of the most relevant of these forest environmental services. In this paper we estimated the economic value of Chilean temperate forests as they contribute to maintain fresh water supply, which in turn supports the production of drinkable water for cities. The study was carried out in the Valdivian Rainforest Ecoregion, in Llancahue watershed, which supplies fresh water to one of the main cities in Southern Chile. Using monthly time series from January 1995 to December 2003, we applied the change in productivity method to derive economic value estimates per cubic meter of water, per household, and per hectare accounting for changes in economic value during summer versus the rest of the year. The economic values per cubic meter were USD 0.066 and USD 0.025 for summer and rest of the year, respectively. The values per household equaled USD 15.4 in the summer and USD 5.8 for the rest of the year. The economic benefits per hectare of native forests were equal to USD 162.4 for summer period and USD 61.2 for the rest of the year.

Keywords: Ecosystem services; Water supply; Economic value; Chilean temperate forest; Drinkable water; Change in productivity method

1. Introduction

Temperate forests of Southern South America continue to impress scientists around the planet due to their rich diversity of life forms, long-lived trees, and high degree of biotic endemism (Arroyo et al., 1996; Armesto et al., 1998). In Chile, they cover 13.4

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0921-8009/$ - see front matter
doi:10.1016/j.ecolecon.2005.08.010

million ha located mostly in the Andes and Coastal Ranges extending for over 2 300 km between 35°S and 56°S. Currently, they represent more than half of the temperate forests remaining in the Southern Hemisphere (Alaback, 1991; Donoso, 1993).

Native forests of Chile and neighboring areas of Argentina, located between 35°S and 48°S correspond to the Valdivian Rainforest Ecoregion, included among the most threatened Ecoregions in the world by the 200 Global initiative of World Wildlife Fund (WWF) and The World Bank (Dinerstein et al., 1995). Some of the temperate forest types located between 36.5°S and 54°S are classified by World Resources Institute (WRI) among the last Frontier Forests in the planet (WRI et al., 2002). Furthermore, the forests located north of 40°S, which continue through Mediterranean and Arid ecosystems up to 25°S, are included among the 25 world biodiversity hotspots (Myers et al., 2000), increasing their conservation value and priority at a global scale.

Chilean temperate forests support fundamental ecosystem services such as internal nutrient cycling, soil protection, biodiversity conservation, climatic regulation, and water supply. They also produce a large variety of timber and non timber products. The provision of these multiple goods and services implies a range of different uses of the forest resources, which may be conflicting, especially when they are not properly accounted for. Competing uses of forests create trade-offs among the multiple components of economic value. Extractive uses such as timber harvest, when not carried out under sustainable schemes, can have large negative impacts on other forest environmental services such as water supply and biodiversity conservation. On the other hand, preservation can create important social costs, especially for local communities when they are not included as part of the forest ecosystem functioning.

Historically, temperate forests in Chile have been mostly considered as a source of timber and firewood, and as land for the expansion of agriculture and pasture following logging and burning. During the last three decades they have also been replaced by fast-growing commercial plantations of exotic species, mainly *Pinus radiata* and *Eucalyptus* spp., declining at rates of 1.1 to 2.7% per year between 1975 and 2000, in some specific areas of the Coastal Range (Echeverría, 2003). Forest destruction and conversion to exotic plantations has had important negative environmental impacts, such as increase in soil erosion and reduction of water quality and supply, and social impacts as forest dwellers and communities have been forced to migrate (Lara and Veblen, 1993).

Among other economic impacts, destruction of native forests may seriously affect economic activities such as recreation, sport fishing, and drinkable water production, since the success of these activities lies on the existence of the services provided by healthy forest ecosystems.

This complicated scenario poses important challenges to forest managers and policy makers regarding the best manner to balance human needs and forest management. In this context, economic benefit estimates obtained from valuation studies can provide important information on the relative scarcity and quality of the environment. As pointed out by Pearce (2001), 'the benchmark principle for forest protection is that the economic values attached to conservation must be greater than the values of alternative uses of the forest resources'. However, many of these values are scarcely known in the case of temperate forests in the Southern Hemisphere.

The World Bank and WWF Alliance for Forest Conservation and Sustainable Use, in its report on the importance of forest for drinkable water, emphasized their potential role in helping to maintain water supply to major cities in the world. A large amount of the water available for the world population as drinkable water comes from existing reserves in natural and artificial forests. Forests regulate quality as well as quantity of water, being the base for an integrated management of hydrological resources in forested watersheds. Hence, water supply provides an important argument for forest sustainable management and protection around the planet (Dudley and Stolton, 2003).

The objective of this study was to determine the economic value of Chilean temperate forests in sustaining the production of drinkable water for human consumption. Using monthly time series we applied the change in productivity method, incorporating stream flow from a forested watershed into a production function of drinkable water for the city of Valdivia, Southern Chile. This approach to environmental valuation has been widely used to value the contribution of natural ecosystems to economic activities.

Several applications in the literature report the value of wetland areas as they support irrigated agriculture, and recreational and commercial fishing (see for example Bell, 1997; Barbier and Strand, 1998; Acharya, 2000; Acharya and Barbier, 2000; Barbier, 2000). Contrarily, its use to estimate forest values is limited.

Our study contributes to this growing literature by applying the change in productivity method to the valuation of temperate forests accounting for changes in economic value during summer months and the rest of the year.

The remaining sections of the paper are organized as follows. Section 2 describes the study area, Section 3 describes the methods and data used, Section 4 provides the main results, and finally Section 5 is dedicated to conclusions.

2. Study area

Llancahue watershed (39° 45′ S, 73° 15′ W), located in the Valdivian Rainforest Ecoregion, Southern Chile, is the main water supply source for Valdivia during most part of the year. It has a total area of 1333 ha of which 60% is represented by old growth forests and 24% by second growth forests, making a total forest area of 1117 ha. The remaining 26% correspond to shrub and open sectors. The dominant tree species belong to the forest types broadleaved Evergreen and Roble–Raulí–Coihue (*Nothofagus obliqua, Nothofagus alpina*, and *Nothofagus dombeyi*), which host a rich variety of other species of fauna and flora (Donoso et al., 2003). Llancahue represents one of the last remnants of the Evergreen forest type of the Central Valley near Valdivia, and has been declared one of 40 priority areas for conservation in the Valdivian Rainforest Ecoregion (Lara et al., 2002).

Llancahue is a discrete watershed, which implies that its drainage network forms one main stream. As such, it provides convenient boundaries especially when the phreatic divides corresponds with the topographic divides and its deep seepage is small or negligible (Likens, 2001). These conditions facilitate the evaluation of inputs and outputs of water and the analysis of mass balance for the watershed-ecosystem.

For the production of drinkable water, the stream water is dammed and conducted by gravity to a treatment plant owned by the firm AguasDécima S.A, located in the outlet of the watershed, supplying drinkable water for 33 000 households in Valdivia.

Annual average precipitation on the watershed reaches 2357 mm, with July being the rainiest month and February the driest (Donoso et al., 2003). Fig. 1 shows the pattern of rainfall and stream water from January 2003 to March 2004. It can be observed that there is a time lag between rainfall and stream water peaks of approximately one month, especially

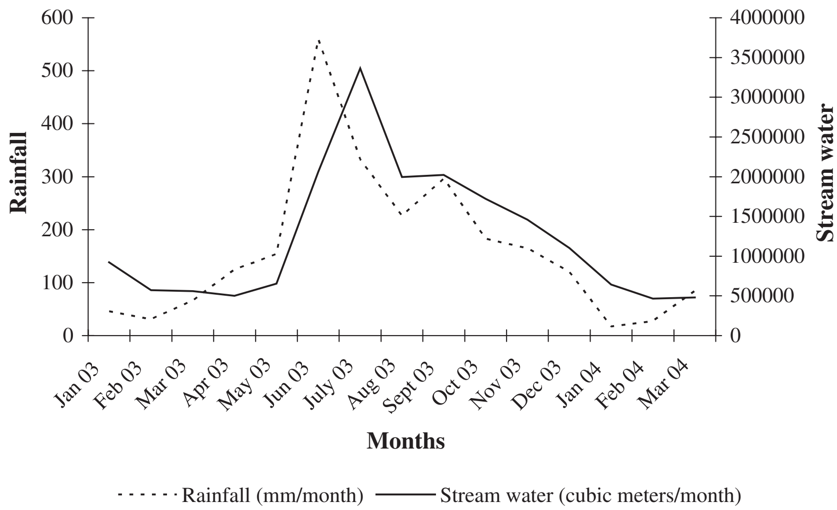

Fig. 1. Rainfall and stream water in Llancahue watershed from January 2003 to March 2004.

noticeable in winter time. This pattern arises from the fact that the major contribution of precipitation to stream water occurs when soil water reserves have been reestablished.

The ecological and economic importance of Llancahue has motivated the interest of the general public, private firms, public institutions and the scientific and academic community for the current and future use of the watershed. Management alternatives are faced with the absence of defined land property rights[1], which causes the continuous pressure by neighboring rural inhabitants who extract timber for firewood and charcoal (Donoso et al., 2003).

Measuring changes in value and economic welfare resulting from forest degradation or conversion to other land uses, can provide an estimate of the benefits associated with the sustainable utilization of this forest ecosystem. In this context, economic valuation can be seen as being among the instruments for decision making regarding the future use of the watershed.

3. Modeling approach and data

3.1. Water supply as an ecosystem service of forests

De Groot et al. (2002) define water supply as 'filtering, retention and storage of water in, mainly, streams, lakes and aquifers'. Filtering is performed by vegetation and soil biota and retention and storage depend on site characteristics such as topography. Water supply also depends on the role of forest ecosystems in the hydrology cycle, but is primarily related to the storage capacity and, secondarily, to the flow of water.

In watersheds covered by native forests, roots and microorganisms of the rizosphere increase soil porosity improving oxygen exchange and water retention capacity. As a consequence, after strong rainfall, flooding decreases and water is released slowly after precipitation has ceased, thus avoiding droughts (Primack et al., 2001).

The temperate rainforests in Southern Chile, largely represented in Llancahue watershed, are dominated by several *Nothofagus* spp. and broadleaved evergreen species that grant the ecosystem a strong buffer capacity to control high flows (Soto and Lara, 2001). Also, the presence of a dense understorey, organic soil horizons, and root biomass in *Nothofagus* spp. forests, would contribute to moderate the flows.

Several studies indicate how land use change may negatively impact fresh water supply, affecting the hydrological cycle (Fuentes, 1994; Dudley and Stolton, 2003). In a review of 94 experimental catchments, Bosch and Hewlett (1982) concluded that coniferous and *Eucalyptus* spp. forests caused larger changes than deciduous hardwoods on water supply. In South Africa, Calder et al. (1997) found that reforestation with exotic species such as *Pinus* spp. and *Eucalyptus* spp. aggravated drought problems by significantly reducing water flows in the dry season. In Europe, Robinson et al. (2003) reported significant changes in flows at the local scale, especially in *Eucalyptus globulus* plantations located in Southern Portugal. In Chile, Otero et al. (1994) and Oyarzún and Huber (1999) showed that *Pinus radiata* and *Eucalyptus* spp. decreased water supply during the summer period. Recently, Oyarzún et al. (in press) conducted an evaluation of the hydrological balance on small watersheds in the Valdivian Rainforest Ecoregion. This research was conducted on seven watersheds with different percentages of area covered by native forests and plantations of *Pinus radiata* and *Eucalyptus* spp. located in the Coastal Range near the city of Valdivia. The study showed a significance decrease in water supply in catchments with exotic plantations, aggravating drought problems by significantly reducing water yield as compared to native forests.

These results are particularly important under a scenario of global climatic change, where precipitation has shown a remarkable decline over the last decades in Southern Chile (Pezoa, 2003).

The decrease in water supply resulting from conversion of native forests to other land uses may have serious negative effects on the availability of market goods, such as drinkable water. In turn, changes in production of market goods will be transmitted to the society through the price system, thus affecting human welfare. These relationships can be captured using the change in productivity method.

[1] In Chile land property rights are owned separately from water rights.

3.2. The change in productivity method

This method, also known as the production function approach, is a kind of surrogate market method for valuation of indirect benefits of ecosystems (Barbier, 2000), through their contribution to support economic activities (Bishop, 1999). This method relates changes in human welfare from the incremental production of a market good to a measurable change in the quantity and/or quality of a natural resource (Mäler, 1992).

The first step in implementing this method is to determine the physical effects of changes in a natural resource or ecological function over an economic activity. Second, the impact of these environmental alterations is valued in terms of the change in the marketed output (Barbier, 2000).

The ecosystem service as environmental variable enters the production function along with other factor inputs used in the production of market goods such as fish, agricultural commodities, or drinkable water. The economic value is calculated as the change in the marginal physical product of the ecosystem service valued at the market price of the good (Mäller, 1992). This method has been widely used to estimate the impact of environmental quality changes on activities that generate a marketable good or service (Mäller, 1992; Bishop, 1999).

Following Freeman and Harrington (1990) and Freeman (2003), a firm i is assumed to have a production function of the type:

$$Q_i = Q_i(X_i, S) \qquad i = 1, \ldots, n \tag{1}$$

where Q_i is the market good of the firm i, X_i is a vector of variable inputs to firm i and S is the ecosystem service given exogenously to the firm. The marginal physical product of all factors of production is assumed to be positive. The firm is assumed to face perfectly elastic supplies for all factor inputs at prices v_1 to v_m.

The industry faces a demand of the type $P = P(Q)$. The social welfare function associated with producing Q , the industry output, is given by:

$$W(x_{11}, \ldots x_{nm}, S) = \int_Q^0 P(u)du - \sum_i \mathbf{V} \times X_i \tag{2}$$

with firms $i = 1$ to n and factor inputs $j = 1$ to m, where $\mathbf{V}$ is the vector of input prices. The integral represents the area under the demand curve for the industry output and the summation corresponds to the cost of the factor inputs. The first order conditions for optimization of the welfare function are:

$$\frac{\partial W}{\partial x_{ij}} = P(Q)\frac{\partial Q}{\partial x_{ij}} - v_j = 0 \tag{3}$$

These first order conditions define input demand functions, an output function, and a social welfare function. By deriving the welfare function with respect to S, the welfare measure is obtained as:

$$\frac{\partial W}{\partial S} = P(Q^*) \times \frac{\partial Q[x^*(S), S]}{\partial S} \tag{4}$$

where asterisks indicate optimal quantities. Eq. (4) indicates that the net welfare gain from an environmental change is, in effect, the value of the marginal physical product of the ecosystem service S in the production function, *ceteris paribus*. For a detailed derivation, see Freeman and Harrington (1990).

In our case study, the relevant production function is a drinkable water function and the ecosystem service as factor input is stream water from Llancahue watershed. Using monthly time series data we estimated the model in Eq. (1) in four different structural forms: linear, polynomial, transcendental logarithmic or translog, and Cobb–Douglas (CD).

The linear and polynomial forms were mainly used to explore general substitution relationships among the inputs, autocorrelation patterns, and general performance of the production function. The translog, although allowing for larger substitution possibilities (Nicholson, 1998), it includes cross products and square terms increasing the number of variables in the model. For the case at hand this was considered a limitation since we had a restricted number of monthly observations (108) and the inclusion of these additional variables reduced the degrees of freedom.

Based on the considerations above and selection criteria such as the determination coefficients, the significance of the parameters, and the Akaike Information Criteria of each model, we selected the CD form. This function assumes varying marginal physical products and constant elasticities of substitution, usually producing a good fit (Acharya and Barbier, 2000). Furthermore, since it combines additive and multiplicative effects among the inputs, it is suitable for the case at hand where factors are used and combined in certain amounts. We estimated the following basic linear specification of the CD production function:

$$lnQ_t = \alpha + \beta_1 lnE_t + \beta_2 lnS_t + \beta_3 lnQ_{t-1} + \beta_4 D_i + \beta_5 D_s + \varepsilon_t \quad (5)$$

where:

- $\ln Q_t$ natural logarithm of drinkable water (m^3/month)
- $\ln E_t$ natural logarithm of electric energy (kw/month)
- $\ln S_t$ natural logarithm of stream water (m^3/month)
- $\ln Q_{t-1}$ natural logarithm of the lagged dependent variable (m^3/month)
- D_i intercept dummy
- D_s slope dummy
- ε_t error term.

Stream water and energy are the primary inputs in drinkable water production. Water is extracted all year round and energy is used permanently to operate the equipments required for water purification.

The water treatment process additionally utilizes other inputs—such as chemical products for purification—and labor. Small amounts of chloride, sulfate, and fluoride are used depending on the quality of the stream water and some of them are not needed in certain time periods. Labor requirements, on the other hand, are covered by permanent workers and do not vary over the year. The fact that these inputs are used in very small or fixed amounts creates estimation problems and for this reason we did not include them in the model.

The lagged dependent variable addressed the autocorrelation present in the data, which was identified through the Likelihood Ratio Test and the Durbin Watson Statistic. Furthermore, this variable took into account the link between current and past production decisions of the firm.

The dummy variables addressed seasonality of the data which was mostly deterministic, according to the results of the test proposed by Miron (1996). This outcome was expected given the natural pattern of rainfall in Southern Chile, which in turn influences stream water in a highly deterministic manner. Rainfall and water supply increase in winter time and decrease in the summer months as shown in Fig. 2 in the following Section.

The intercept dummy D_i equaled 1 in the driest summer months (January, February and March) and 0 the rest of the year. This variable accounts for the fact that when stream water diminishes, there is a subsequent decrease in drinkable water production.

The slope dummy $D_s = D_i \times ln\ S_t$, captures the effect that water scarcity in summer should increase the marginal physical product of stream water and, consequently, the economic value of water.

With the variables expressed in natural logarithms, the beta coefficients attached to $\ln E_t$ and $\ln S_t$ in Eq. (5) were interpreted as input elasticities, where β_1 is

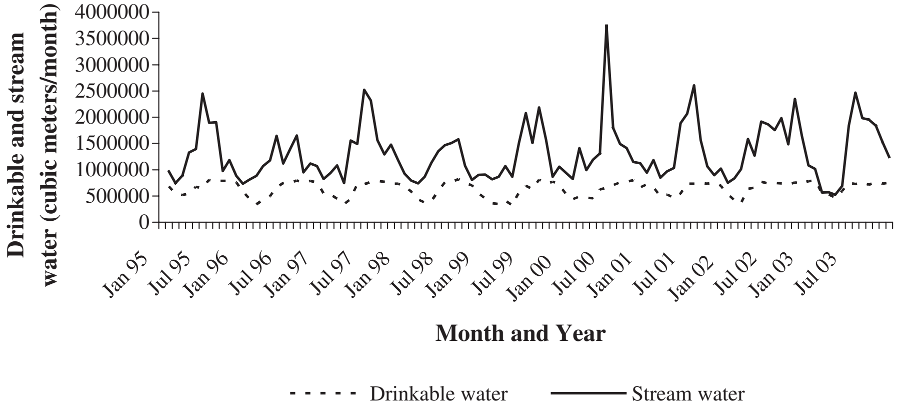

Fig. 2. Drinkable water production and stream water in Llancahue watershed during the study period, January 1995 to December 2003.

the input elasticity of energy, and β_2 and $(\beta_2+\beta_5)$ are the input elasticity of stream water in the rest of the year and summer, respectively.

The marginal physical product of stream water, evaluated at the mean values of drinkable ($\bar{Q}$) and stream water ($\bar{S}$), was calculated as:

$$\frac{\partial Q}{\partial S} = \frac{\partial lnQ}{\partial lnS} \times \frac{\bar{Q}}{\bar{S}} = (\beta_2 + \beta_5) \times \frac{\bar{Q}}{\bar{S}} = \bar{\omega} \quad \text{for summer period} \qquad (6)$$

$$\frac{\partial Q}{\partial S} = \frac{\partial lnQ}{\partial lnS} \times \frac{\bar{Q}}{\bar{S}} = \beta_2 \times \frac{\bar{Q}}{\bar{S}} = \bar{\omega} \quad \text{for the rest of the year} \qquad (7)$$

From the marginal physical products in Eq. (6) and (7), we calculated annual economic values, which can be interpreted as the welfare loss resulting from decreases in stream water supply and consequently drinkable water. Economic value estimates were obtained as $\bar{\omega} \times P$, where P is the market price of drinkable water. These values were calculated per cubic meter, per household and per hectare.

3.3. Data

Data on drinkable water production, factor inputs, and prices from January 1995 to December 2003, were collected from AguasDécima S.A. data base.

The market price we used was equal to USD 0.35/m^3 of drinkable water that corresponds to an average of the real prices registered during the study period (January 1995 to December 2003). This price reflects the variable costs of the firm adjusted by the consumer price index and other indexes relevant to the national economy. To express the results in USD we used an average of the exchange rate reported by the Central Bank of Chile (2004) for the study period, equal to Chilean Pesos $615 per USD.

Stream water level was measured daily with staff gauges and calibrated periodically with standard techniques. To derive the stage–discharge relationship, stream water discharge was measured several times from 2002 to 2004 using the velocity–area method (Schulz, 1989). After this calibration, we reconstructed the time series of stream water for the period 1995–2003, with a regression model between precipitation and discharge.

The estimation of the production function was conducted in MICROFIT 4.1 using autoregressive techniques to account for the presence of a lagged dependent variable. We used the Gauss–Newton iterative routine, which provides Maximum Likelihood estimates of the model in Eq. (5).

4. Results and discussion

4.1. Parameters of the model

Table 1 shows the results of the estimation of the CD production function. The overall significance of the model was assessed using the determination coefficient R^2 (0.78) and the F-test that was statistically significant at the 1% level. Both measures demonstrated that the model fitted the data well.[2]

The parameters on stream water and energy correspond to input elasticities and were significant at all conventional levels with the expected positive signs, indicating that both inputs increase output production. The stream water coefficient was equal to 0.155, implying that a 10% change in stream flow causes a 1.5% change in production of drinkable water. This value may seem low given the importance of the stream water as factor input in the production of drinkable water. However, this reflects that only a portion of the stream water available during the year is captured and used, especially in winter months. This difference is largest in July of each year (Fig. 2). On average, the stream water of Llancahue was equal to 1 322 784 m^3 per month and the drinkable water produced was 634 834 m^3 per month during the study period.

The input elasticity of energy was positive and equal to 0.102 indicating that a 10% change in energy use causes a 1% change in production of drinkable water.

The lagged dependent variable had a significant positive sign reflecting that over time, the current production of drinkable water relates directly to past production decisions.

[2] The linear, polynomial and translog models also exhibited a good performance, with coefficients of similar magnitude and the same signs as the CD function, supporting the robustness of the results.

Table 1
Estimates of the Cobb–Douglas production function of drinkable water

Variables	Parameters	Standard errors	t-ratio	p-values
Constant	2.045*	0.837	2.443	0.016
ln E	0.102**	0.033	3.019	0.003
ln S	0.155**	0.035	4.384	0.000
ln Q_{t-1}	0.618**	0.051	12.096	0.000
D_i (intercept dummy)	−3.657*	1.539	−2.376	0.019
D_s (slope dummy)	0.256*	0.111	2.294	0.024
R^2	0.78			
Adjusted R^2	0.77			
F-stat	62.01 (0.000)			
No. of observations	107†			
DW-statistic	1.98			

For coefficients of covariates ** and * indicate t significant at $P<1$ and 5%, respectively.
† One observation is lost in the estimation due to the inclusion of a lagged dependent variable.

The intercept and seasonal dummy variables were significant at the 5% level. The coefficient on D_i was negative (−3.657) supporting that drinkable water production was significantly smaller in summer as expected, due to lower summer flows. The positive coefficient on D_s (0.256) demonstrates that when stream water becomes scarcer its marginal physical product and, consequently, its economic value increases significantly.

From the parameters in Table 1 we calculated the marginal physical product of stream water using Eqs. (6) and (7) for summer and the rest of the year, respectively. The results obtained equaled 0.19 for summer and 0.07 for the rest of the year. These results imply that if stream water changes by 1 m^3, drinkable water will change by 0.19 m^3 in summer and by 0.07 m^3 in the rest of the year.

4.2. Changes in welfare

Table 2 shows the annual economic value associated with the decrease in water supply in Llancahue watershed per cubic meter, per household, and per hectare.

The economic value per cubic meter of stream water in summer and the rest of the year was calculated as the product of the marginal physical product of stream water in every period and the price of drinkable water. The resulting values were USD 0.066 and USD 0.025 for summer and rest of the year, respectively.

The value per household was calculated multiplying the above results by the average annual production of drinkable water equal to 7 618 078 m^3 for the study period, and dividing by the total number of households in the city of Valdivia, which equals 33 000. The results obtained were USD 15.4 in summer and USD 5.8 the rest of the year.

The calculations of annual economic values per ha were based on the results reported by Oyarzún et al. (in press) that show the inverse relationship between the percentage of native forest cover and stream flow, for watersheds in the Valdivian Ecoregion similar to Llancahue in terms of structure and site conditions. Based on their findings, we estimated that water supply would decrease by an average of 27 127 cubic meters per year when the area of native forests in the watershed decreases by 1% and it is replaced by plantations of *Pinus radiata* or *Eucalyptus* spp. This reduction in stream flow is associated to a reduction in drinkable water in a magnitude given by the marginal physical product. Our calculations show that a 1% change in cover in Llancahue from native forests to exotic plantations, causes drinkable water to decrease by 5 154 m^3 in summer and 1 898 m^3 in the rest of the year. Taking into account an area of 1 117 ha of native forests in Llancahue, we obtained economic values per ha equal to USD 162.4 in summer and USD 61.2 in the rest of the year.

This large difference in economic values in summer compared to the rest of the year is an evidence of the relevant ecological role of temperate forests in periods of water scarcity. This role is particularly important under a scenario of declining precipitation in Southern Chile, which provides an important argument for sustainable management and conservation of these ecosystems.

Table 2
Estimates of annual economic values per cubic meter of water, per household, and per hectare of native forest in Llancahue watershed

Period	Value/m^3 (USD)	Value/household (USD)	Value/ha (USD)
Summer	0.066	15.439	162.4
Rest of the year	0.025	5.819	61.2

Whereas the negative consequences of changes in land use in a watershed are well known, the economic valuation of water supply at specific sites is complex due to the heterogeneity of forest structure, geography and climatic conditions, which can explain the varying results in the literature.

Among the few studies that report the economic value of native forests in water supply, Kumari (1996) considered the protection of irrigation water in Malaysian forests for agricultural crops obtaining an annual value of USD 15 per ha. Bann (1999), using contingent valuation, valued shoreline and fishery protection by Malaysian mangrove forests reporting annual values of USD 845 and USD 526 per ha, respectively. Clinch (1999) valued water supply by Irish temperate forests, obtaining a negative annual economic value of USD -20 per ha. In Brazil, Torras (2000) estimated the annual value of water regulation contributed by the Amazonian forests in USD 19 per ha. In Guatemala, Hernández et al. (2002) reported an annual value for water regulation by tropical forests of USD 202 per ha.

It is important to note that although some of these values seem to be low, in per ha basis, watershed areas can be very large and therefore these values are aggregated across vast sectors.

5. Conclusions

Temperate forests provide a multiplicity of ecosystem goods and services that can have significant economic value at a local and global scale. In Chile the lack of information on the magnitude and value of these benefits has promoted extractive uses over sustainable forest management and conservation.

In this study we estimated the indirect use value of temperate forests in the Valdivian Rainforest Ecoregion, Southern Chile as they support the production of water for human consumption.

We used the change in productivity method and a Cobb–Douglas production function to model the production of drinkable water including energy and stream water as factor inputs and an intercept and a slope dummy to account for changes in the marginal physical product of stream water during summer and the rest of the year. The input parameters were both significant and positive. The coefficients on the intercept dummy was negative indicating that water production was smaller in summer as expected due to the lower summer flows. The slope dummy parameter was positive indicating that marginal physical product of stream water was higher in summer as compared to the rest of the year, which relates to water scarcity during periods of low stream flows.

The economic values per cubic meter were USD 0.066 and USD 0.025 for summer and rest of the year, respectively. The values per household equaled USD 15.4 in the summer and USD 5.8 in the rest of the year. Finally, the economic benefits per ha of native forests were equal to USD 162.4 for summer period and USD 61.2 for the rest of the year.

These results provide preliminary information, which nevertheless, may serve to strengthen the necessary public awareness to develop a strong national forest policy for Chilean native forest.

Acknowledgments

The authors wish to thank Forest Ecosystemic Services to Aquatic Systems under Climatic Fluctuations (FORECOS P04-065-F), a Millennium Scientific Initiative Nucleus of the Chilean Ministry of Planning and Fundación Andes Chile (C-13960/47), for their financial and technical assistance to this research work.

References

Acharya, G., 2000. The values of wetlands: landscape and institutional perspectives. Ecol. Econ. 35, 63–74.

Acharya, G., Barbier, E., 2000. Valuing groundwater recharge through agricultural production in the Hadejia-Nguru wetlands in North Nigeria. Agric. Econ. 22, 247–259.

Alaback, P.B., 1991. Comparative ecology of temperate rainforests of the Americas along analogous climatic gradients. Rev. Chil. Hist. Nat. 64, 399–412.

Armesto, J.J., Rozzi, R., Smith-Ramírez, C., Arroyo, M.K., 1998. Conservation targets in South American temperate forests. Science 282, 1271–1272.

Arroyo, M.K., Riveros, M., Peñaloza, A., Cavieres, L., Faggi, A.M., 1996. History and regional richness patterns of the cool temperate rainforest flora of Southern South America. In: Lawford, R.G., Alaback, P., Fuentes, E.R. (Eds.), High Latitude Rain Forest and Associated Ecosystems of the West Coast of the

Americas: Climate, Hydrology, Ecology and Conservation. Springer-Verlag, Berlin, pp. 134–172.
Bann, C., 1999. A contingent valuation of the mangroves of Benut, Johor State, Malaysia. Report to DANCED, Copenhagen.
Barbier, E., 2000. Valuing the environment as input: review of applications to mangrove–fishery linkages. Ecol. Econ. 35, 47–61.
Barbier, E., Strand, I., 1998. Valuing mangrove–fishery linkages: a case study of Campeche, Mexico. Environ. Resour. Econ. 12, 151–166.
Bell, F., 1997. The economic value of saltwater marsh supporting marine recreational fishing in the Southeastern United States. Ecol. Econ. 21, 243–254.
Bishop, J., 1999. Valuing Forests: a review of methods and applications in developing countries. Environmental Economics Program International Institute for Environment and Development (IIED), July 1999. http://www.worldbank.org.
Bosch, J., Hewlett, J., 1982. A review of catchments experiments to determine the effects of vegetation changes on water yield and evapotranspiration. J. Hydrol. 55, 3–23.
Calder, I.R., Rosier, P.T., Prasanna, K.T., Parameswarappa, S., 1997. Eucalyptus water use greater than rainfall input—a possible explanation from southern India. Hydrol. Earth Syst Sci. 1, 249–256.
Central Bank of Chile, 2004. Cotización del Dolar Observado. http://www.bcentral.cl/esp/infoeconomica/seriesindicadores/xls/Dolar_observado.xls.
Clinch, J.P., 1999. Economics of Irish Forestry: Evaluating the Returns to Economy and Society. COFORD, Dublin. 300 pp.
De Groot, R., Wilson, M., Boumans, R., 2002. A typology for the classification, descriptions and valuation of ecosystem functions, goods and services. Ecol. Econ. 41, 393–408.
Dinerstein, E., Olson, D., Graham, D., Webster, A., Primm, S., Bookbinder, M., Ledec, G., 1995. A Conservation Assessment of the Terrestrial Eco-Regions of Latin America and the Caribbean. WWF-World Bank. 129 pp.
Donoso, C., 1993. Ecología de los Bosques Templados de Chile y Argentina. Editorial Universitaria, Santiago, Chile. 484 pp.
Donoso, P., Little, C., Neira, E., Reyes, R., Rutherford, P., Zamorano, C., 2003. Plan de desarrollo integral para el predio Llancahue, Valdivia, Chile. Propuesta Técnica Instituto de Silvicultura, Facultad de Ciencias Forestales, Universidad Austral de Chile.
Dudley, N., Stolton, S., 2003. Running pure: the importance of forest protected areas to drinking water. Alliance for Forest Conservation and Sustainable Use. World Bank/World Wildlife Fund, United Kingdom (112 pp).
Echeverría, C., 2003. Deforestation and Forest Fragmentation of Temperate Forests in Chile. Dissertation University of Cambridge. Fitzwilliam College, Cambridge. Master of Philosophy. 111 pp.
Freeman, A.M. III, 2003. The measurement of environmental and resource values, Theory and Methods, Second edition. Resources for the Future, Washington. 491 pp.
Freeman III, A.M., Harrington, W., 1990. Measuring welfare values of productivity changes. Southern Econ. J. 56 (4), 892–904.
Fuentes, E., 1994. ¿Qué futuro tienen nuestros bosques? Hacia la gestión sustentable del centro y sur de Chile. Ediciones Universidad Católica de Chile. 290 pp.
Hernández, O., Cobos, C., Ortiz, A., 2002. Valoración Ambiental del Servicio Ambiental de Regulación Hídrica. http://www.congresocuencas.org.pe/pdf/PONENCIAS/21.valoración-económica-RBSM-sur-final.pdf.
Kumari, K., 1996. Sustainable forest management: myth or reality?. Exploring the prospect for Malaysia. Ambio 25, 459–467.
Lara, A., Veblen, T., 1993. Forest plantations in Chile: a successful model? In: Mather III, A. (Ed.), Afforestation: Policies, Planning and Progress. Belhaven Press, London, pp. 119–137.
Lara, A., Echeverría, C., Reyes, R., 2002. Bosques Nativos. In: Instituto de Asuntos Públicos, Universidad de Chile. (Eds.), Informe País. Estado del Medio Ambiente en Chile. Santiago, Chile. 127–160.
Likens, G.E., 2001. Biogeochemistry, the watershed approach: some uses and limitations. Mar. Freshw. Res. 52, 5–12.
Mäller, K.-G., 1992. The production function approach in developing countries. In: Vincent, J., Crawford, E., Hoehn, J. (Eds.), Valuing Environmental Benefits in Developing Economies. Seminar Proceedings, Michigan State University Graduate Specialization in Resource Economics, East Lansing, Michigan, U.S.A.
Miron, J., 1996. The Economics of Seasonal Cycles. MIT Press, Cambridge. 288 pp.
Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 408, 853–858.
Nicholson, W., 1998. Microeconomic Theory. Basic Principles and Extensions. The Dryden Press, Orlando, pp. 320–321.
Otero, L., Contreras, A., Barrales, L., 1994. Efectos ambientales del reemplazo de bosque nativo por plantaciones (Estudio en cuatro microcuencas en la provincia de Valdivia). Cienc. Invest. For. 8, 252–276.
Oyarzún, C.E., Huber, A., 1999. Water balance in young plantations of *Eucalyptus globulus* and *Pinus rad*iata in Southern Chile. Terra 17, 35–44.
Oyarzún, C., Nahuelhual, L., Núñez, D., in press. Los servicios ecosistémicos del bosque templado lluvioso: producción de agua y su valoración económica. Ambiente y Desarrollo.
Pearce, D., 2001. The economic value of forest ecosystems. Ecosyst. health 7, 284–296.
Pezoa, L., 2003. Recopilación y análisis de la variación de las temperaturas (período 1965–2001) y las precipitaciones (período 1931–2001) a partir de la información de estaciones meteorológicas de Chile entre los 33° y 53° de latitud Sur. Tesis Facultad Ciencias Forestales, Universidad Austral de Chile. Valdivia, Chile.
Primack, R., Rozzi, R., Feinsinger, P., Dirzo, R., Massardo, F., 2001. Fundamentos de conservación biológica. Perspectivas LatinoamericanasFondo de Cultura Económica, México. 797 pp.
Robinson, M., Cognard-Plancq, A.-L., Cosandey, C., David, J., Durand, P., Fuhrer, H.-W., Hall, R., Hendriques, M.O., Marc, V., McCarthy, R., McDonell, M., Martin, C., Nisbet, T., O'Dea, P., Rodgers, M., Zollner, A., 2003. Studies of the impacts of forests on peak flows and base flows: a European perspective. For. Ecol. Manag. 186, 85–97.

Schulz, E.F., 1989. Problems in Applied Hydrology. Water Resources Publications, Colorado, U.S.A.

Soto, D., Lara, A., 2001. Servicios Ecosistémicos de los Bosques Nativos. In: Primack, R., Rozzi, R., Feinsinger, P., Dirzo, R., Massardo, y F. (Eds.), Fundamentos de Conservación Biológica: Perspectivas Latinoamericanas. Fondo de Cultura Económica, México D.F., pp. 295–297.

Torras, M., 2000. The total economic value of Amazonian deforestation, 1978-1993. Ecol. Econ. 33, 283–297.

WRI (World Resource Institute), CODEFF (Comité pro defensa de la flora y fauna) and Universidad Austral de Chile, 2002. Chile's frontier forests: conserving a global treasure. A global Forest Watch Report. Chile.