Forest and water: The value of native temperate forests in supplying water for human consumption: A comment

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A B S T R A C T

In a recent paper in this journal Nuñez et al. [Nuñez, D., L. Nahuelhual, and C. Oyarzun, 2005. Forest and water: the value of native temperate forests in supplying water for human consumption. Ecological Economics 58: 606–616] presented a model to estimate the economic value of Chilean temperate forests in their function to contribute to maintain fresh water supply. We discuss and correct the estimated values of ecosystem services per household and per hectare.

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1. Introduction

Using the ‘change in productivity method’ Nuñez et al. (2006) (hereafter NNO) estimated the economic benefits provided by Chilean native temperate forests through the supply of naturally filtered water (‘stream water’) used as an input for the production of water for human consumption (‘potable water’). As a measure of these benefits, NNO calculated a sort of a willingness to pay (WTP) of the average family for a given annual amount of “stream water” generated by the forest wish in turn supports the annual production of “potable water”. Additionally, they calculated the annual economic value of the ecosystem service (provision of “stream water”) generated by a hectare of natural forest.

According to the method, to estimate the WTP per family for the forest ecosystem service, first, NNO determine the physical effect provoked by a reduction in the provision of naturally filtered water over the production of potable water. Second, they calculate the value of the forest’s ecosystem service as the reduction in the market value of the output (potable water) resulting from that physical impact. In this fashion, they obtain the economic marginal value of a cubic meter of stream water as an input in the production of drinkable water (i.e. USD 0.066 and USD 0.025 per m^3 of stream water during the summer and the rest of the year, respectively). Third, to estimate the average family’s WTP for the forest ecosystem service (for summer and for the rest of the year), NNO multiply these calculated values by the annual production of potable water and then, they divide the annual total

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values obtained by the total number of families living in the area of influence.

However, after the first two steps the authors obtain the marginal values (for the summer and the rest of the year) of a cubic meter of 'stream water', i.e., the value of a marginal cubic meter of input used in the production function of the final product, 'potable water'. Therefore, in their third step, for calculating the total values of the input provided by the native forest in both, the summer and the rest of the year, NNO should have multiplied their calculated marginal values of the input by the total amount of naturally produced stream water rather than by the amount of man-produced drinkable water (to obtain the total values of the stream water to be divided by the number of families in the area of influence). We demonstrate here that this mistake results in that NNO underestimated in more than 100% the economic value the ecosystem service provided by the native temperate forest.

Additionally, in order to estimate the annual economic value of the ecosystem service per hectare of natural forest, NNO used a transformation function between native forest and exotic plantations of pines and calculated the net benefit per hectare, reporting the marginal benefit per hectare of native forest less its marginal cost (the opportunity cost of plantations). This procedure is incorrect since it is the gross benefit (not the net benefit) per hectare that has to be calculated regardless the alternative uses of the forest cover.

2. The change in productivity method

As it is shown below, the change in productivity method allows to calculate the change in welfare (ΔW) provoked by a non-marginal change in an input of production ('stream water' here), through its impact over the production of a final product ('potable water' here). Theoretically those who benefit from the contribution of the input to the production of the output would pay for the former at most the value of the welfare loss provoked to them by not having the input. This is what NNO assimilates to a WTP measure for the input ('stream water') economic value.

Following Freeman and Harrington (1990) and Freeman (2003), a firm i is assumed to have a production function $Q_i=Q_i(X_i, S)$, $i=1,\ldots, n$, where Q_i is the market good of the firm i (corresponding to potable water in NNO context), X_i is a vector of m variable inputs used by firm i and S is the ecosystem service or the production input (the stream of naturally filtered water in NNO context) exogenously provided to the firm by the native temperate forest. The firm is assumed to face perfectly elastic supplies for the m factor inputs at prices υ_1 to υ_m.

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

$$W(x_{11},\ldots\ldots,x_{nm},S)=\int_{Q}^{0}P(u)\mathrm{d}u-\sum_{i}\mathrm{V}x\boldsymbol{X}_{i} \tag{1}$$

with firms indexed $i=1$ to n and factor inputs $j=1$ to m, and where V is the vector of input prices. The integral represents the area under the demand curve for the industry's output and the summation corresponds to the industry's total costs of factor inputs.

The first order conditions for optimization of the welfare function are:

$$\frac{\partial W}{\partial x_{ij}}=P(Q)\frac{\partial Q}{\partial x_{ij}}-\upsilon_j=0. \tag{2}$$

These first order conditions provide the analytical expressions for the m input demand functions, the output function, and the social welfare function. By deriving the welfare function with respect to S, the welfare measure of a marginal change in the provision of the ecosystem service (stream water) is obtained:

$$\frac{\partial W}{\partial S}=P(Q^*)\frac{\partial Q[x^*(S),S]}{\partial S}=\upsilon_S \tag{3}$$

where, υ_S corresponds to the marginal value of a cubic meter of "stream water", which in a competitive economy with explicit markets for all $m+1$ inputs would also correspond to the market price of input S.

From Eq. (3), and following Boyd and Banzhaf (2006), the effect on welfare of a discrete (non-marginal) change in the ecosystem service can be expressed as:

$$\Delta W=P\Delta S\frac{\partial Q}{\partial S}=\upsilon_S\Delta S. \tag{4}$$

Eq. (4) shows that to calculate the total annual (welfare) value of the input 'stream water' one can multiply the total annual amount of 'stream water' (i.e., replacing S^* for ΔS in the last term of the equation) by its marginal value υ_S. In their paper, NNO erroneously multiplied υ_S by Q^*, the annual amount of the man-made final product drinkable water instead of by S^*. This results in a large underestimation of the economic value of the ecosystem service ('stream water') provided by the temperate forest calculated by NNO, as it is shown in the next section.

3. Estimation of a non-marginal change in ecosystem services

The total benefits of a non-marginal change in the quantity of the ecosystem service can be found integrating Eq. (3)

$$\Delta W=\int_{S_0}^{S_0+\Delta S}P(Q^*)\frac{\partial Q}{\partial S}\mathrm{d}S \tag{5}$$

where S_0 corresponds to some aggregative quantity of the ecosystem service while ΔS corresponds to a non-marginal change in the ecosystem service as the one shown in Fig. 1, where:

$$\Delta W=a+b. \tag{6}$$

To calculate ΔW using Eq. (5) two procedures are generally used. One is to calculate the area b in Fig. 1 by $\upsilon_S\Delta S$, which obviously implies a larger underestimation of area $a+b$ the larger is area a (which in turn depends on the size of ΔS and on the input price elasticity). The second, procedure is to assume that $\partial^2Q/\partial S^2=0$, i.e. that $Q/S=\partial Q/\partial S=$a constant, and therefore, area $a=0$ since the value marginal product curve for the ecosystem service S ($P\partial Q/\partial S$) is a horizontal line. Since NNO do not impose this assumption they must calculate $\upsilon_S\Delta S$. Moreover, given that NNO assume perfect elastic demand for drinkable water, consumer surplus is zero, and therefore ΔW is actually the change only in producer surplus due to the

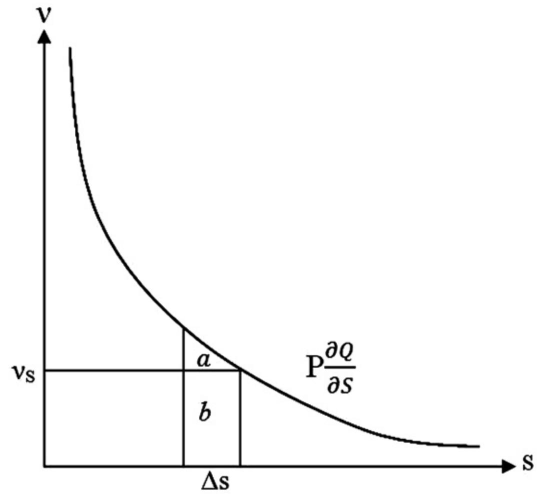

Fig. 1 – Welfare change from a discrete change in ecosystem services.

incremental availability of naturally filtered water for the production of potable water. This change in producer surplus is approximated by the area *b* in the graph and it corresponds to the amount of money that the producer of potable water would pay if a well developed market for naturally filtered water (temperate forest's ecosystem service) exits.

NNO wrongly estimated the change in welfare ΔW multiplying the price of 1 m^3 of stream water, v_S, times the average annual production of drinkable water ΔQ (=7,618,078 m^3) obtaining a value of USD 502,793 in summer and USD 190,452 in the rest of the year (NNO page 613). Then, they divided these values by the 33,000 households in Valdivia City to obtain the yearly values per household reported in their Table 2 (page 613) and reproduced here in Table 1 below (i.e. USD 15.439 and 5.819 in summer and the rest of the year, respectively).

However, according to Fig. 1 and Eq. (4), the right procedure to estimate the change in welfare ΔW is to multiply v_S times the average annual production of stream water ΔS (=15,873,408 m^3). Therefore, the annual economic value of the ecosystem service is USD 1,047,645 in summer and USD 396,835 in the rest of the year. These values divided by the number of households in the area of influence (33,000 households) result in the values reported in column four of Table 1, that correspond to the correct economic annual value per household of the ecosystem service (provision of naturally filtered stream water) generated by the native forest. As it is shown in the last column of Table 1, the mistake made by NNO in calculating ΔW implied an underestimation of the real economic value of the ecosystem provided by the native temperate forest of more than 140% for summer and more than 100% for the rest of the year.

Since the provision of the ecosystem service 'stream water' by the native forest critically depends on the area covered by this type of forest, it is interesting to calculate the value of the ecosystem service provided by hectare of native forest (*H*).

Eq. (3) allows us to obtain an analytical expression to calculate the annual economic value of ecosystem service S per ha of forest:

$$\frac{\partial W}{\partial H} = P(Q^*)\frac{\partial Q[x^*(S), S]}{\partial S} * \frac{\partial S}{\partial H} = v_S\frac{\partial S}{\partial H} = v_H. \tag{7}$$

Eq. (7) now explicitly presents the role of forest cover *H* as an input in the production of raw water S, and shows that its marginal welfare contribution through the provision of 'stream water' for the production of 'potable water' is v_H. Moreover, $v_H = v_S \partial S/\partial H$, and since NNO had calculated v_H (see second column of Table 1 above), they only needed to estimate $\partial S/\partial H$. This partial derivative was estimated by NNO using Oyarzun et al. (2005), who calculated that 'stream water' supply decreases by an average of 27,127 m^3 per year when the area of native forest in the watershed decreases by 1% and is replaced by plantations of pines or eucalyptus. Given the size of the Llancahue watershed (1117 has), 1% corresponds to 11.17 hectares and therefore, $\partial S/\partial H = 2429$ (=27,127/11.17). Using this value, and the value of the marginal product of stream water, the authors estimate in USD 162.4 and USD 61.2 the total annual value of ecosystem service per hectare of native forest for the summer and the rest of the year, respectively.

However, these values strongly underestimate the real benefits associated to the native forest cover since it merely reflects the net (net of opportunity cost) benefit rather than the gross benefit generated by an increment in the hectares of native forest (through the increased in the provision of the ecosystem service 'stream water'). In what follows we present a procedure that allows to estimate the gross benefits per hectare of native forest and that it is also consistent with the other parameters estimated by NNO (particularly the estimation of the WTP per household).

According to Eq. (7) and similarly to the derivation of Eq. (4), the effect on welfare of a change in the ecosystem service S measured through ΔS or alternatively through ΔH can be approximated by:

$$\Delta W = v_S \Delta S = v_H \Delta H \tag{8}$$

and consistently can be estimated by $v_H = (v_S \Delta S/\Delta H)$. For the NNO context, ΔS corresponds to the average annual production of stream water, ΔH to the total area of Llancahue watershed and v_S has the values reported in the second column of Table 1 above, both for the summer and the rest of the year. The re-estimated values together with the original values reported by NNO are presented in Table 2.

Table 1 – Economic value of a marginal m^3 of 'stream water' provided by native temperate forest, household WTP for the annual ecosystem service received as calculated by NNO and as corrected here

Period	Stream water marginal value (USD/m^3)	Household WTP as calculated by NNO (USD/year)	Household WTP as corrected here (USD/year)	Difference (%)
Summer	0.066	15.4	31.7	140.9
Rest of the year	0.025	5.8	12.0	106.9

Table 2 – Economic value of a marginal hectare of native temperate forest, as calculated by NNO and as corrected here

Period	Welfare value of a hectare of native forest as calculated by NNO (USD/year)	Welfare value of a hectare of native forest as calculated here (USD/year)	Difference %
Summer	162.4	937.9	477.5
Rest of the year	61.2	355.3	480.5

Column 4 of Table 2 shows that NNO underestimated the contribution of a hectare of native temperate forest through the provision of the ecosystem service 'stream water' in more than 470% for the summer and more than 480% for the rest of the year. Correcting the mistakes made by NNO in their calculations can be critical when using benefit transfer technique, as Figueroa (2007) did for estimating the value of ecosystem services contribution of the National System of Protected Areas for the Chilean population.

REFERENCES

Boyd, J., Banzhaf, S., 2006. What are ecosystem services? The need for standardized environmental accounting units. Discussion Paper No. RFF DP 06-02. Resources for the Future.

Figueroa, 2007. Estudio "Análisis económico y estudio de factibilidad para el financiamiento del Sistema de Áreas Protegidas", Informe Final. For PNUD-GEF-World Bank and CED. April 23. Santiago, Chile.

Freeman III, A.M., 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. South. Econ. J. 56 (4), 892–904.

Nuñez, D., Nahuelhual, L., Oyarzun, C., 2006. Forest and water: the value of native temperate forests in supplying water for human consumption. Ecol. Econ. 58, 606–616.

Oyarzun, C., Nahuelhual, L., Nunez, D., 2005. Los servicios ecosistemicos del bosque templado lluvioso: produccion de agua y su valoracion economica. Ambiente Desarro. 21, 88–95.