

# Water provision as an ecosystem service of native forests compared to exotic forest plantations in Southern Chile.

Antonio Lara<sup>1,2</sup>, Christian Little<sup>1,2</sup>, Rocío Urrutia<sup>1,2</sup>, James McPhee<sup>3</sup> and Camila Alvarez<sup>3</sup>

(1) Instituto de Silvicultura, Facultad de Ciencias Forestales y Recursos Naturales, Universidad Austral de Chile, Casilla 567, Valdivia (Chile), [antoniolara@uach.cl](mailto:antoniolara@uach.cl), (2) Fundación FORECOS, (3) Departamento de Ingeniería Civil, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Blanco Encalada 2002, Santiago, Chile.

Native forests of the Valdivian Rainforest Eco-region in Chile (35°-48° S), are among those with the highest conservation priority worldwide and provide important ecosystem services. This study quantifies water supply as an ecosystem service from native forests. Monitoring of six watersheds between 2003 and 2006 showed that the annual runoff coefficient (quickflow/precipitation, Qq/P) and total streamflow/summer precipitation were significantly correlated with native forest cover in the watershed ( $R^2=0.67$  and  $0.76$ , respectively,  $P<0.05$ ). Conversely, the annual runoff coefficient was negatively correlated with the exotic plantation cover ( $R^2=0.59$ ,  $P=0.072$ ). Comparison of 2003-2006 streamflow between a watershed with thinned native forest and a control paired watershed, showed that the thinned forest had 19.7% and 40% greater annual and summer streamflow, respectively. These studies demonstrate one of the significant impacts land use change has on streamflow and provides crucial information on the potential use of native forest cover to conserve or increase streamflow in Chile and elsewhere.

Keywords: Land use change, Ecological restoration, Forest policy

## Introduction

Native forests in Chile cover 13,4 million hectares and due to their diversity, high degree of endemisms and threats have been classified among those with the highest conservation priority worldwide (Olson and Dinerstein, 1998). These forests are dominated by evergreen and deciduous *Nothofagus* as well as by several evergreen broadleaved species. Native forests continue to be degraded and cleared for their conversion mainly to fast-growing *Pinus radiata* and *Eucalyptus spp* exotic plantations and to a lesser extent to agriculture and pasturelands. The vision of native forest solely as a source of timber, firewood and land to be converted to other land uses has neglected their value to provide key ecosystem services to society. On-going research in Chile has demonstrated the importance of native forests in the provision of ecosystem services (ES). Such services include water supply, tourism and recreational fishing opportunities, and the maintenance of soil fertility which are crucial for economic development and social welfare (Lara et al., 2003; Nahuelhual et al. 2007; and Lara et al. 2009). ES provide a great potential to align economic development objectives with ecosystem conservation.

In this paper, we describe the results of a long-term ecosystem research started in 2002 to quantify streamflow as an ecosystem service from native forests compared to exotic forest plantations, both in small and large watersheds. We also discuss the effects of forest management (thinning) on streamflow and an ongoing experiment to recover water quantity and quality through the restoration of native forests. Finally we provide some policy recommendations from our research.

## Water provision and forest cover in small watersheds.

Six watersheds ranging from 140 to 1,460 ha in the Valdivia area (39° 50' – 40°05' S) with an annual rainfall of 1,700 – 2,200 mm having different proportions of native forests and *Eucalyptus spp* and *P. radiata* plantations were selected for recording streamflow during four hydrological years (April 2003 – March 2007, Lara et al. 2009). Streamflow was recorded daily from the observation of staff-gages. Stage-discharge relationships were developed using the velocity-area method. Results show that the annual runoff coefficient (quickflow/precipitation, Qq/P) was significantly correlated with native forest cover in the watershed ( $R^2=0.67$ ,  $P=0.045$ , Fig 1a). The inverse relationship was found for exotic plantation cover, with the annual runoff coefficient decreasing as the area of exotic plantations increased ( $R^2=0.59$ ,  $P=0.072$ , Fig 1b, Lara et al, 2009).

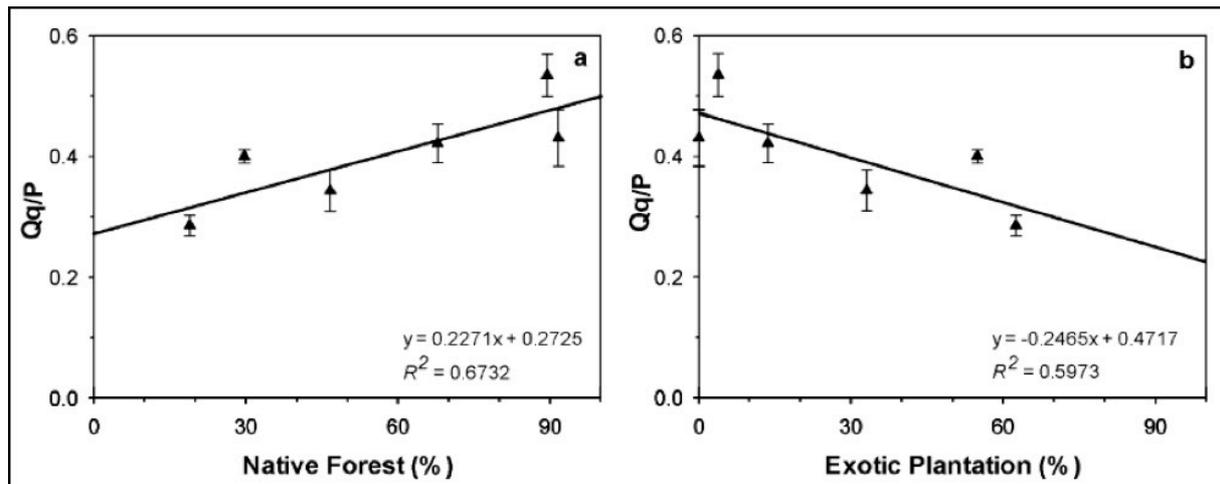


Fig 1. (a) Relationship between mean annual direct runoff coefficient (quickflow/precipitation) and native forest cover (%) in six catchments. (b) same for exotic plantation. Vertical bars represent standard errors.

### Water provision and forest cover in large watersheds

Many studies from different regions of the world have documented that in small watersheds (<20 km<sup>2</sup>) fast-growing forest plantations reduce water yield. Nevertheless, these effects have not been adequately documented in large watersheds (i.e. >100 km<sup>2</sup>). The temporal variation of the residuals between best-fit precipitation–runoff relationships and instrumental streamflow records for two large watersheds in the period 1961–2004 was examined (Little et al. 2009). The Purapel en Nirivilo (PPN, 252.5 km<sup>2</sup>) and Cauquenes en el Arrayán (CQA, 707.7 km<sup>2</sup>) watersheds were selected for this study. These watersheds are located in the coastal range of South-Central Chile under a Mediterranean-climate with an annual precipitation ranging from 717 and 835 mm (85% in April through September) and with a high interannual variability. Landsat imagery shows a decline in native forest cover from 52.3% to 14.2% for PPN and 36.1% to 8.1% in CQA, between 1975 and 2000 (Figure 2). This reduction was mainly due to the conversion of native forests dominated by deciduous *Nothofagus* spp to *Pinus radiata* plantations, which have increased from 12% to 55% in PPN, and 4.7% to 42% in CQA in the period 1975–2000.

A decreasing trend in summer runoff residuals regressed against annual precipitation in the same period, with slopes significantly different from zero was observed for PPN ( $P = 0.035$ ) and CQA ( $P = 0.008$ ). This pattern was interpreted as an evidence of change in the hydrological regime in these watersheds as a consequence of forest cover and land-use changes. From a reanalysis of the observed data we estimated a decrease in the mean summer runoff from 13.1 to 7.5 mm (i.e. -42%) for PPN and from 7.3 to 5 mm (i.e. -33%) for CQA in the period 1991–2000 compared to 1981–1990 (Figure 3, Little et al. 2009). Multiple regression analyses of annual and seasonal flows showed that in addition to precipitation, the percentage-cover of forest plantations is a statistically significant predictor of summer flow with a partial negative correlation of -0.45 and -0.44 for PPN and CQA, respectively,  $P < 0.05$ . This study clearly shows the important effect that land-use change can have on water provision as a key ecosystem service and to our knowledge this is the first study documenting the decrease in summer runoff in large watersheds (i.e. >100 km<sup>2</sup>), where native forest cover has been dramatically converted to forest exotic plantations. Similar methods could be used elsewhere to inform policy and decisionmaking regarding forest and land-use planning.

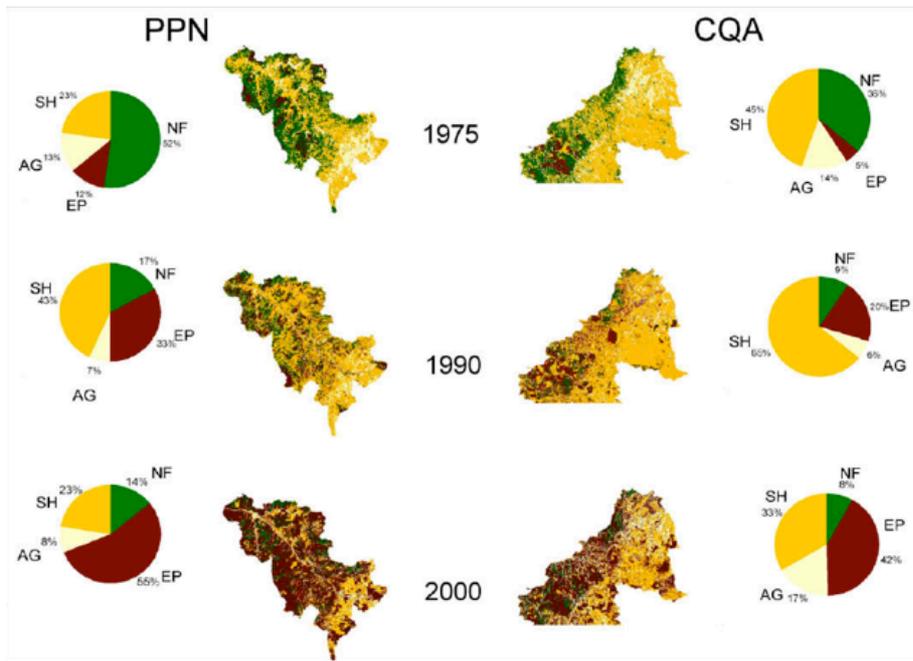


Fig. 2. Changes in forest cover in the Purapel en Nirivilo (PPN) and Cauquenes en el Arrayán (CQA) watersheds in 1975, 1990 and 2000.

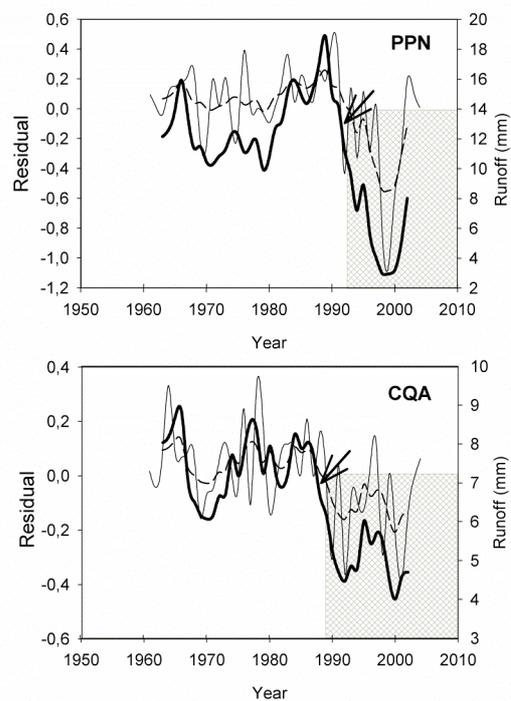


Fig 3. Residuals of the summer runoff (December to March) from its regression against annual precipitation during 1961 to 2004 (thin solid line) for PPN and CQA. The trend line of the residuals from a moving-average smoothed is shown in dashed line. Bold solid lines represent the temporal change in total summer runoff predicted by an equation developed from the observed data. The arrows indicate the mean runoff value between 1961-2004 and the shaded areas represent the period with negative residuals estimated by a moving-average smoothed.

## **Forest management and streamflow**

A study was developed in two watersheds (12.6 and 7.4 hectares in area) covered with second-growth forests. The first watershed was thinned extracting 35% of the total basal area for the production of roundwood, whereas the other one remained unthinned as a control. Streamflow was recorded in V-notch 90°-section gauges following standard procedures (Ward and Trimble, 2004) during four hydrological years (April 2003 to March 2007, Lara et al, 2009). Results showed that the thinned watershed yielded higher stream discharge values compared to the control during the four years of observation (Fig. 4). The difference in annual discharge between both watersheds was 19.7%, and in the dry summer season was 40% (Lara et al., 2009). The higher reduction in canopy interception and evapotranspiration in the thinned watershed compared to the control and a relatively faster depletion of soil and water table reserves in the control watershed through the summer probably explains this difference.

## **Re-establishment of the forest ecosystem service of water provision by ecological restoration in south-central Chile**

Previous studies analyzing 6 watersheds in the Valdivian Rainforest eco-region have demonstrated the positive correlation between streamflow with the percentage of native forest cover, with a mean increase of 14.1% in total summer streamflow for every 10% increase in native forest cover (Lara et al. 2009). This evidence was the basis for the establishment of a long-term research program to examine whether the conversion of exotic *Eucalyptus* plantations back to native forest could recover this water provision function. This experiment started in 2006 involves nine small (0.9 - 123 ha) experimental watersheds located in Reserva Costera Valdiviana, proposed as a Long Term Ecosystem Research site in southern Chile (40°S, 73.5° W). After five years of hydrologic monitoring, a positive significant correlation between streamflow and native forest cover in the watersheds have been found. A negative significant correlation between suspended solids in the stream water and the width of the riparian strips of native forests surrounded by *Eucalyptus* plantations was also reported. After this 5 years of calibration period, in February 2011, four watersheds covered with plantations were clearcut (a total of 15 hectares) and will be subjected to passive and active restoration programs. This, through the plantation and natural regeneration of the native forest species that are present in the area. This experiment integrates the concepts and methods of ecological restoration with ecosystem services and it will indicate the potential of large-scale restoration programs to re-establish water supply through planting native forests. This on-going, collaborative research has important policy implications and involves several institutions, integrating social, economic and environmental dimensions in a transdisciplinary approach.

## **Policy implications**

Results presented in this paper highlight the importance of water provision as an ecosystem service from native forests that is key for the society welfare and how this service have been deteriorated due to the massive conversion of native forests to fast-growing *Pinus radiata* and *Eucalyptus spp* plantations since 1975. This problem is stressed by the observed and projected trends in precipitation for south-central and southern Chile, estimated by regional climatic models in a 25 – 40% reduction by year 2100 (Fuenzalida et al 2007). Another important stress is the increase in water demand for human consumption, irrigation, tourism, introduced salmon farming and hydropower generation.

The gradual decrease in water availability, especially in the dry summer season, due to climatic trends and land-use changes, indicates the urgent need for a policy that effectively promotes the conservation, restoration and sustainable management of these forests. The law on native forests approved by the Chilean congress in July 2008, which includes subsidies for thinnings, plantation and protection, should be an important instrument to promote the management and conservation of these forests. Nevertheless, the impact of these subsidies in promoting water provision and other relevant ecosystem services is limited since the law does not include specific incentives or payment schemes for these services.

Research and the pilot study presented here are the basis to propose a large scale restoration plan for

native forests in South-central Chile to create balanced landscapes with an adequate proportion of forest plantations and native forests in the watersheds, in order to allow the compatible production of timber and water provision (quantity and quality). This landscape restoration plan requires the active involvement and investment from both the private and public sectors. This is especially true since more than 60% of the plantations are owned by two large private holdings.

The National Strategy for the Adaptation to Climatic Change should include the conservation, restoration and sustainable management of native forests as one of the most promising adaptation actions. This is supported by research results presented here indicating that water yield can be incremented (especially in summer) by the increase of native forests cover in the watersheds, and by thinning of second growth forests. The landscape transformation plan towards a landscape with a higher proportion of native forests compared to the present situation, should be a key component of the Strategy for the Adaptation to Climatic Change.

## References

- Fuenzalida, H., P. Aceituno, M. Falvey, R. Garreaud, M. Rojas, & R. Sanchez 2007. Study on climate variability for Chile during the 21st century. Technical Report prepared for the National Environmental Committee. Santiago, Chile. In Spanish. Available on-line at <http://www.dgf.uchile.cl/PRECIS> (August 2007). Lara, A., Soto, D., Armesto, J., Donoso, P., Wernli, C., Nahuelhual, L. and Squeo, F., 2003. Componentes científicos clave para una política nacional sobre usos, servicios y conservación de los bosques nativos Chilenos. Universidad Austral de Chile, Valdivia.
- Lara, A., Little, C., Urrutia, R., McPhee, J., Álvarez-Garretón, C., Oyarzún, C., Soto, D., Donoso, P., Nahuelhual, L., Pino, M., Arismendi, I. 2009. Assessment of ecosystem services as an opportunity for the conservation and management of native forests in Chile. *Forest Ecology and Management* 258: 415-424
- Little, C., Lara, A., McPhee, J., Urrutia, R. 2009. Revealing the impact of forest exotic plantations on water yield in large scale watersheds in South-Central Chile. *Journal of Hydrology* 374:162-170.
- Nahuelhual, L., Donoso, P., Lara, A., Núñez, D., Oyarzún, C., Neira, E., 2007. Valuing ecosystem services of Chilean temperate rainforests. *Environment, Development and Sustainability* 9: 481–499.
- Olson, D., Dinerstein, E., 1998. The Global 200: a representation approach to conserving the Earth's most biologically valuable ecoregions. *Conservation Biology* 12: 502–515.
- Ward, A.D., Trimble, S.W., 2004. *Environmental Hydrology*. Lewis Publishers/CRC Press Company, London/New York, 472 pp.