

Landscape Ecology

Balancing water supply and old-growth forest conservation in the lowlands of south-central Chile through an adaptive co-management approach

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Abstract:	<p>Balancing the provision of ecosystem services in the urban-rural interface is a complex issue due to increasing demands from multiple stakeholders in both urban and rural communities. This is the case for medium-sized, water-supply watersheds for important cities in south-central Chile that are remnant native forests surrounded by a land matrix dominated by plantations of exotic species or agriculture. These remnant native forests provide important ecosystem services such as clean water, protection of biodiversity, and peri-urban parks, but face pressure from both urban and rural communities that illegally use the properties for activities such as logging and grazing of animals. One such case is the Llancahue watershed (1270 ha) that provides fresh water to the city of Valdivia (130,000 inhabitants) and protects > 700 ha of old-growth forest. The Universidad Austral de Chile received the watershed as a concession from the state in 2008 at which point illegal logging and grazing were threatening the integrity of the ecosystem functions provided by the watershed. The goal is to protect and improve important ecosystem services provided by the Llancahue watershed through a multi-step process. First, there was a need to understand stakeholders' views towards the project. Then an ecosystem management plan for the watershed was developed from this information that promoted an adaptive co-management approach. This has included zoning the watershed to balance multiple societal demands and ecosystem functions from the watershed. This paper reports results after four years of implementation, and provides perspectives on the ecosystem management approach.</p>
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Balancing water supply and old-growth forest conservation in the lowlands of south-central Chile through an adaptive co-management approach

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Abstract

Balancing the provision of ecosystem services in the urban-rural interface is a complex issue due to increasing demands from multiple stakeholders in both urban and rural communities. This is the case for medium-sized, water-supply watersheds for important cities in south-
5 central Chile that are remnant native forests surrounded by a land matrix dominated by plantations of exotic species or agriculture. These remnant native forests provide important ecosystem services such as clean water, protection of biodiversity, and peri-urban parks, but face pressure from both urban and rural communities that illegally use the properties for activities such as logging and grazing of animals. One such case is the Llancahue watershed
10 (1270 ha) that provides fresh water to the city of Valdivia (130,000 inhabitants) and protects > 700 ha of old-growth forest. The Universidad Austral de Chile received the watershed as a concession from the state in 2008 at which point illegal logging and grazing were threatening the integrity of the ecosystem functions provided by the watershed. The goal is to protect and improve important ecosystem services provided by the Llancahue watershed through a multi-
15 step process. First, there was a need to understand stakeholders' views towards the project. Then an ecosystem management plan for the watershed was developed from this information that promoted an adaptive co-management approach. This has included zoning the watershed to balance multiple societal demands and ecosystem functions from the watershed. This paper reports results after four years of implementation, and provides perspectives on the ecosystem
20 management approach.

Key Words: Silviculture, ecological thinning, community-based conservation, Valdivian Ecoregion, hydrologic monitoring, old-growth forest attributes

Introduction

The global interest in describing and evaluating ecosystem services during the last
25 decades in many countries throughout the world derives from the recognition that they are
fundamental for human welfare and well-being, and therefore it is necessary to apply an
ecosystem approach to management (Costanza et al. 1997; Millennium Ecosystem
Assessment (MEA) 2005). Ecosystem management (EM) has resulted from the recognition
that management of specific environmental targets and ecosystem services requires an
30 understanding of landscape processes and the spatial scales that maintain those targets and
services (Jones et al 2012). EM approaches involve actors who interact to solve problems,
make decisions and undertake actions while implementing monitoring to evaluate the effects
of specific landscape management decisions on ecosystem services (Jones et al 2012) Often,
EM requires collaborative approaches such as adaptive co-management, a form of
35 decentralized conservation that embraces a complex, socioecological systems perspective and
holds the promise of improving on-the-ground conservation by involving multiple
stakeholders in the land management process (Folke et al 2007; Olsson et al 2007).

One practical scale at which to promote EM through adaptive co-management is the
watershed scale (García et al 2005). Watersheds have been cited as the most appropriate land
40 management unit to maintain the health, functioning and conservation of ecosystems (Likens
2001). Studies at the level of small- or medium-sized watersheds allow scientists to account
for flows and fluxes of matter and energy in the system by monitoring chemical and physical
variables (Hedin and Campos 1991, Likens and Bormann 1995, Likens 2001). Forests have
been hypothesized to best protect ecosystem services in a watershed, and therefore forest
45 management in watersheds should be designed so that it best satisfies the multiple ecosystem
services demanded by society, i.e. clean drinking water, protection of biodiversity and old-
growth forests, recreation and wood products (Nahuelhual et al 2007). EM at the watershed

scale allows the coordinated use of land, water and related components with the aim of maximizing social welfare in an equitable manner without compromising the sustainability of the ecosystems (Montgomery et al 1995, Cotler 2004, FAO 2007).

EM encourages forest management at different scales to sustain ecosystem resilience and diversity by promoting or conserving structural heterogeneity and biological legacies (Drever et al 2006). Unfortunately, the current trend in Latin America is one of poor forest management with the consequent loss of native forests and degradation of ecosystem services (FAO 2010). Chile is not an exemption to this Latin American trend. In a comprehensive study of the forest sector in Chile, Donoso and Otero (2006) concluded that the country is still in a stage of forest regulation , i.e. there are lots of forest management regulations, but this does not necessarily guarantee forest management practices conducive to protecting ecosystem services (*sensu* McGingley et al 2012). In Chile, the government provides weak enforcement of the regulations, lacks a supportive institutional and policy environment, and is rigid to change and adaptation (Donoso and Otero 2006, Newton et al 2009).

Currently, Chile has 13.4 million ha of native forests from the central part of the country to the extreme south. This includes the Valdivian Temperate Rainforest Ecoregion (35–48°S) which is a forested ecosystem with a worldwide high conservation priority (Olson and Dinerstein 1998). Within this Ecoregion, > 2 million ha of plantations of *Pinus radiata* and *Eucalyptus* sp. have been established in the intermediate depression and foothills of the Cordilleras, replacing large tracts of native forests (Echeverría et al 2006; Lara et al 2009; Armesto et al 2010; Nahuelhual et al 2012). Thus, only small, patches of native forests remain in this low- and mid-elevation lands. Many of these forests have been set aside as conservation areas by the Chilean government for the purpose of protecting water supplies, but these government-owned watersheds are being conserved on paper only due to insufficient funding for on-the-ground management. Currently, many of these remnant

forests are threatened by illegal uses from neighboring communities such as illegal timber harvesting and grazing of animals (McNeely 1994, Armesto et al. 1996, Moorman et al 2013, 75 and references therein). For this reason, in Chile like many other Latin American countries an increased emphasis must be given to managing forests to improve livelihoods and conserve ecosystem services (Newton et al 2009). Recent evaluations of ecosystem services provided by watersheds of native forests in Chile have illustrated the value of properly managing these ecosystems. Well-managed native forests produce higher water yields than poorly managed 80 native forests or watersheds that have been converted to non-native forest plantations (Núñez et al 2006, Nahuelhual et al 2007; Lara et al 2009).

Armesto et al (2010) stated that to prevent further depletion of native forest resources in developing nations, like Chile, the goal should be to promote ecosystem management of diverse forests within landscapes and fostering diverse cultural relationships between people 85 and their land. This requires on-ground operational models for implementing conservation actions that account for the needs of local communities. Here we report and discuss the model followed in the case of the Llancahue watershed, a medium-sized protected area dominated by old-growth native forests of high diversity and productivity in the urban-rural interface in south-central Chile. An adaptive co-management approach has been adopted with the goal of 90 sustaining multiple ecosystem services from this watershed. This is a unique case in Chile because it consists of a multidisciplinary research team working with multiple stakeholders to promote the conservation of water and biodiversity of a highly-valued protected area (Moorman et al 2013). The objectives of this study were to: 1) assess the Llancahue watershed planning advances in social intervention, forest management and hydrologic 95 monitoring; 2) discuss the successes and challenges of using an adaptive co-management approach to sustain and improve ecosystem services within the watershed

Methodology

Study area

100 South-central Chile is characterized by a rural landscape dominated by agricultural and
grazing fields in the lower lands of the central valley or intermediate depression, but during
the last decades there has been an increasing presence of *Pinus radiata* and *Eucalyptus* sp.
plantations in these areas and in the foothills of both mountain ranges (Cordillera de los
Andes and the Coastal Cordillera) (Figure 1). Secondary forests of native species still exist in
105 these low- and mid-elevation lands, but old-growth forests are nearly gone (Armesto et al
2009). Within the intermediate depression near the city of Valdivia is the Llancahue
watershed (1270 ha), a remnant native forest within a landscape matrix surrounded by
industrial plantations and small degraded properties owned by the Lomas del Sol community
(Figure 2). Llancahue is an important conservation area because it provides water to the city
110 of Valdivia (130,000 inhabitants; Núñez et al 2006) and protects more than 700 ha of old-
growth forest (Figure 3). The Universidad Austral de Chile (UACH) received the watershed as
a concession from the State in 2008 at which point illegal logging and grazing were
threatening the integrity of the watershed. The University's goals are to (1) protect quantity
and quality of the water supply, (2) conserve biodiversity in the watershed, (3) encourage
115 public use through outdoor education and ecotourism, (4) conduct scientific research on
ecosystem processes, and (5) manage and finance the project through forest management
(Moorman et al 2013). A steering committee accompanies the UACH in this process, which
includes five public institutions, one NGO (Agrupación de Ingenieros Forestales por el
Bosque Nativo - AIFBN), the Municipality of Valdivia, and the Lomas del Sol community of
120 23 campesino families (campesino is a Spanish word that means rural peasant).

The climate of the region is humid and temperate. The weather station at 25 m a.s.l. in
the Valdivia city has a mean annual temperature of 12.0 °C (January mean=17.0°C, July

mean=7.6°C), and a mean annual precipitation of 2,280 mm. Rainfall is concentrated during the winter period from May to August (62%) and decreases significantly during the summer period from January to March (9%) (see also Núñez et al 2006 for further information).

Social intervention

It was recognized early that the project's success hinged on our ability to engage the Lomas del Sol community into the project. In order to accomplish this, methods from the Participatory Action Research model were employed (Villasante 2003, FAO 2007).

Participatory Action Research is a process developed for working with local communities that aims to develop questions, experiments, and disseminate the knowledge necessary to understand the problems and find socially acceptable solutions. The first step of implementing this process was to conduct two semi-structured interviews in the Lomas del Sol community during years 2008 and 2009, one to understand the origins and socio-economic characteristics of the community (Ponce and Barrientos 2009; 56 residents from 15 out of 23 households), and the other to know their uses of Llancahue and their willingness to work with UACH to collaboratively manage Llancahue (Moorman 2010; 20 residents from 15 of the 23 households). All data were member-checked with the community and any discrepancies were corrected.

This information from this social diagnosis was then used to develop a watershed planning by a multidisciplinary team of experts and professionals). This plan included the interests of stakeholders which have been identified elsewhere (Moorman et al., 2013) and the economic needs of campesinos of Lomas del Sol that are discussed here. The goal of the plan was to implement an ecosystem management approach in Llancahue with the local Lomas del Sol community without compromising the provision of water quality and quantity. Through time, the diagnosis has been refined and improved through meetings between the Lomas del Sol community, the UACH and the AIFBN, allowing additional key information to be

included in the watershed plan and to support the decision-making process. This facilitated the construction of a vision of territory which allowed the implementation of an action plan with priorities and activities in Llancahue and its surrounding landscape.

Zoning

Following the methodology of Oltremari and Thelen (2003) for planning protected areas, we identified zones with homogeneous management objectives in Llancahue. Zoning of was initially delimited with the aid of a LIDAR image in conjunction with the corresponding Digital Elevation Model, and considered land cover (forest cover, hydrologic network, topography, and trail networks). The information and comments from stakeholders enriched this initial proposal to arrive to five zones (Figure 4): 1) Primitive, which included most of the old-growth forests and lands surrounding the main water course of the watershed; 2) Restoration, in the northeast side of the watershed that has been subjected to past intensive uses and is covered by scrubs dominated by the highly competitive bamboo *Chusquea quila*; 3) Intensive, aimed for public use and located where the public road connects the Llancahue watershed in its southeastern side in an area with gentle slopes, a variety of native forests, and a clear view to the landscape; 4) Extensive, which includes a trail through the center of a 100-m wide strip in the watershed that allows trekking longer distances, visiting restoration and management zones, and connecting with the most majestic old-growth forests; and 5) Management, which is neighbor to the Lomas del Sol community, covered mostly with dense 70-80 years old secondary forests, and restricted to slopes <30%.

Forest management and silvicultural approach

The management zone includes mostly second-growth forests (Figure 4) which are characteristic in the lowlands of south-central Chile including a) mixed-evergreen forest which is a mixture of 20 evergreen tree species lacking *Nothofagus*; b) *Nothofagus dombeyi*-dominated forest, and; c) *Drimys winteri*-dominated forest. In addition, Llancahue has two

types of old-growth forests dominated by hardwood species, with one type is dominated by emergent *N. dombeyi* trees. These old-growth forests serve as reference ecosystems that can be used to manage secondary forests through ecological or restorative thinnings that have the primary aim of increasing attributes of old-growth forests in secondary forest as a means to provide ecosystem services expected from old-growth forests in these secondary forests (Keeton 2006, Bauhus et al 2009, Dwyer et al 2010). These attributes include an increase in the proportion of successional species, the promotion of better growth rates to reach large diameters, the development of a rich understory and new regeneration cohorts, the increase of vertical structure, the development of increased wildlife habitat, and the creation of dead wood in the system (snags and coarse woody debris) (Bailey and Tappeiner 1998, Acker et al 1998, Bauhus et al 2009).

We hypothesize that the rates at which these three types of secondary forests will reach old-growth attributes is variable (Table 1). We evaluated differences between secondary- and old-growth forests in terms of number of trees, tree species richness, basal area, basal area of trees >80 cm, and structural heterogeneity through the Gini Coefficient (Lexerød y Eid, 2006), which calculates from basal area values the deviation from perfect equality, where 0 is the minimum value that indicates that all individuals have the same size, and 1 is the maximum value that shows that all individuals have different sizes (values $\geq 0,7$ indicate a heterogeneous structure). We sampled three plots of 900 m² for each of the five types of forests. In addition, we thinned six plots of the same size in each of the three second-growth forest types; Three plots received a crown thinning, i.e. a traditional thinning type in many hardwood forests in temperate regions (*sensu* Nyland 2002), and the other three plots received an ecological thinning. These ecological thinnings left a residual density of 50%, as compared to a residual density of 60-65% that is usually left following crown thinnings of these forests.

#Table 1 approximately here#

Hydrologic monitoring

200 Nine experimental catchments were selected in the study area (Figure 3), three catchments were distributed amongst each of the three main land cover types: 1) evergreen old-growth forests, 2) evergreen secondary forests, one of which was thinned on January 2013, and 3) scrubs dominated by *C. quila* (Table 2). Rainfall was recorded with three rain gauges connected to HOBO data loggers (Ben Meadows Company). The gauges had a resolution of
205 0.25 mm and provided information about the number, duration, and volume of rain events. The three rain gauges were installed in open areas with no trees within a 20 m radius from the instruments. Runoff was recorded hourly with a diver pressure transducer in V-notch weirs (60°) installed in the lower part of each catchment following standard procedures (Ward and Trimble 2004). To estimate the amount of water involved in evapotranspiration we used the
210 water balance equation, based on the principle of mass continuity for forest ecosystems (Feller 1981): $ET = Pp - Q$, where ET: total evapotranspiration, Pp: rainfall and Q: runoff
#Table 2 approximately here#

Results

215 Social intervention

Interviews with the Lomas del Sol community (n=15) highlighted that there are no jobs in the community other than occasional, temporary forestry work. Residents produce charcoal and firewood as their primary income source. Despite the fact that charcoal and firewood production were the two main economic activities in Lomas del Sol, only three of the
220 households claimed to get all of their wood from their own property. All of these owned more than 10 ha, including planted eucalyptus or pine. Most households (n=13) have few of their

own forest resources remaining, forcing them to rely on Llancahue and other nearby properties for wood extraction and cattle grazing. On the majority of the properties, timber had been harvested and not replanted. Residents claimed they did not have the technical skills or resources to improve the condition of their own land.

The primary benefit that the community expected from the Llancahue project was creation of jobs. All of the households interviewed that had adults who were not retired wanted and needed work (n=14). When asked what work they would prefer, 11 of the 20 surveyed residents stated they would prefer to continue participating in forestry vocations such as thinning the forest, cleaning the forest, and trail building. In general, respondents would accept a salary of \$364 a month in exchange for their work on the Llancahue project (average response was around \$200,000 CLP). The community was also interested in education, training, and better community services as part of this project. Further, the poor access to the territory, and the lack of electricity, created a bleak outlook at the onset of the project. Given this scenario, the project team worked with the campesinos to implement better infrastructure and provide technical assistance and training focused on teaching productive practices to the families of Lomas del Sol, and to enhance capabilities through collective organization (Table 3). In addition, men in the community were hired to work in forest thinnings which provided much needed income to Lomas del Sol families and engaged the men in appropriate forest management. Forest management planning within Llancahue took an adaptive co-management approach by including the UACH Institute of Silviculture, the AIFBN and Lomas del Sol community members in the planning process. Campesinos of Lomas del Sol learned about the benefits of ecosystem management approach and how it could benefit the Llancahue watershed while receiving revenue for participating in the ecological thinnings. In addition, negotiations with the local government were conducted to improve access to Lomas del Sol.

#Table 3 approximately here#

Forest management and silviculture

The two old-growth forests and the three secondary forests differ in most variables evaluated, with the largest difference being that generally the secondary forests have more trees and more tree species, but less basal area and large trees, and a lower Gini coefficient indicating poorer structural heterogeneity (Table 4). This means that management of secondary forests has to promote the creation of large trees and increase heterogeneity. Within the forest management zone (Figure 4), an average of 12 ha/yr have been managed. The experimental plots used to test the short term yields of ecological thinnings as compared to those from crown thinnings showed that ecological thinnings resulted in residual densities similar or lower than with crown thinnings, and in these plots thinning intensities were greater since original relative densities were slightly higher (Table 5). In spite of the differences among the three second-growth forests in terms of numbers of trees, basal area and Quadratic Stand Diameter (QSD), the volumes harvested, in this case mostly for fuelwood, ranged between 44 and 74 m per ha, except for ecological thinnings in the *D. winteri* plots where the mean volume harvested was higher due to the partial harvest of some legacy old trees. In other words, while second-growth forests mainly provide fuelwood due to the small mean diameters of the trees, harvested volumes are similar among secondary forests due to a reciprocal relationship between tree volume (higher in *N. dombeyi* secondary forests) and the numbers of trees (higher in *D. winteri* and Mixed secondary forests). Harvested volumes did not seem to differ between thinning types, since although ecological thinnings are meant to leave a lower residual density they also leave structural legacies such as standing large live trees, girdled trees to become snags, and coarse woody debris from felled trees.

270 #Table 4 approximately here#

#Table 5 approximately here#

Hydrologic monitoring

The hydrologic monitoring was initially established in second-growth forests dominated by *Nothofagus*, so there are preliminary data of runoff and precipitation. During 275 the period September 2011 through January 2013 (Figure 5), the water yield was 1364 mm, with minimum values at summer (2 mm day^{-1}) and maximum in winter (14.7 mm day^{-1}). Total ET for the period was 942 mm, who was estimated from the residual of watershed mass-balance equation. ET increases during summers and decay through winters, which 280 indicates an overall loss of water from the forest ecosystem of 40% in relation to the incident precipitation (water potentially available in the ecosystem). Total ET values estimated should be understood as the sum of transpiration by trees and evaporation from all forest strata, from the floor to the tree crowns. This estimate assumes that deep drainage and change in catchment storage are negligible between years and that the annual precipitation recorded is a reasonable estimate of spatially distributed precipitation over the watershed.

285

Discussion

Multidisciplinary and adaptive co-management for conservation of ecosystem services

Llancahue, the largest protected area in the Intermediate Depression of south-central Chile has been managed for the last four years by the UACH in conjunction with a steering 290 committee where the main participants have been the AIFBN and the Lomas del Sol campesino community. This has been a process in evolution which had to begin with an understanding of the beliefs, positions, interests, and concerns of the stakeholders (Moorman et al 2013). Land-use decisions have been taken by weighing the need to satisfy human demands and the unintended ecosystem responses based on societal values (*sensu* DeFries et

295 al 2004) through an adaptive co-management approach that allows for a continuous
improvement of ecosystem understanding. This has meant the implementation of specific
ecosystem management practices, some with the Lomas del Sol community, to meet the
initial objectives of conserving relevant ecosystem services demanded by the stakeholders,
mainly provision of fresh water, conservation of old-growth forests, and timber supply, and
300 monitoring the impacts of all management actions for the purpose of ensuring that
management actions lead to desired conservation results.

We feel it is important to emphasize the complexity of implementing an experimental
management process with many unknowns (i.e. community integration, impacts of forest
management, lack of funding). Llancahue represents a complex and valuable social-ecological
305 system and for that reason it has been invited to become part of the Long-Term Social-
Ecological Research sites in Chile (LTSER-Chile). We recognize that the science to support
initial decisions on ecosystem management is incomplete, often with high levels of
uncertainty about potential outcomes (See Jones et al 2012, and references therein), and
consider that the key to conduct this process has been working with a multidisciplinary
310 research team to respond to the multiple complexities of an ecological setting where human
populations and societal demands cross (Szaro 1998, Risser and Iverson 2013).

One major challenge for this project has been a lack of economic resources for project
implementation. The nearly lack of support from the State (central and local) to rural
development and the scarcity of funds for conservation projects generates a gap in State
315 development strategies at the local scale. Despite the important ecosystem services provided
by the Llancahue watershed, there is no current economic mechanism provided by the state or
the private water company for improving services such as the provision of water (Núñez et al
2006). However, we have been able to implement positive conservation practices with funds
from forest management and four large research and development projects financed by

320 national and international grants, including one granted to the AIFBN from the European
Union (SGP/UNDP, EU). One benefit of implementing ecosystem management practices is
that it provides a dependable source of income for conservation and development projects.
We also expect that increasing involvement of professionals and researchers is likely to
continue bringing research and development projects to Llancahue. The case of Llancahue can
325 be contrasted against other more expensive, top-down initiatives aimed at promoting
conservation that have not been effective because they have lacked a rigorous design of the
programs to be implemented and a continuous monitoring of the environmental and social
benefits of these programs (Bowler et al. 2012).

330 Monitoring land cover-water interactions and effects of forest management

Many regions in the world are dominated by secondary forests. These secondary forests are
capable of providing ecosystem services associated with old-growth forest if forest
management shifts its focus from producing timber and leaving the most commercial trees to
also leaving and promoting more heterogeneous structures. Active forest management is
335 necessary when timber production is one of the interests stated by some stakeholders, which
is usually the norm, even when these forests are in protected areas (Franklin 2003). This is
especially relevant where old-growth forests are scarce or have nearly disappeared, like in the
lowlands of central Chile and elsewhere.

If the purpose of a forest is to protect a water supply it is important to insure that any
340 timber management activities happening within the forest will not have a negative impact.
Hydrologic monitoring is an effective tool for evaluating the impact of productive practices in
real time, and provides relevant learning for decision making in the management cycle. In
Llancahue we have set a network of watersheds (Figure 3 and Table 2) to evaluate water
quality and yields in catchments of different land cover, some with and without forest

345 management through ecological thinning. Based on work from some previous studies (Lara
et al 2009, Oyarzún et al 2009) we expect an increase in water yield in managed forests in
small catchments, especially during summer months. One of the main drivers on these
changes is ET (Díaz et al. 2007), which is affected by canopy cover or basal area at the stand
level and by the physiological characteristics of the vegetation, successional state and soil
350 cover (Huber and Iroumé 2001). Management of secondary forests can increase water yields
in the watershed by reducing canopy interception and soil cover (Díaz et al 2007), and
decreasing the abundance of species with higher potential ET (i.e. *Nothofagus*; Huber et al
1983) in favor of species that have lower rates of transpiration and higher values of water use
efficiency (i.e. *Aextoxicon punctatum* and *Laureliopsis philippiana*; Oyarzún et al 2012). To
355 better elucidate the effects of forest management on ET, it would be useful to separate it into
its primary components of evaporation, sublimation, and transpiration to understand the
dominant hydrologic processes that produced yield changes. Ultimately, there are a number of
hydrologic processes that may be altered as a result of the effects of management. To improve
our understanding of how the magnitudes of the specific components of the water balance are
360 altered, additional empirical work focused on canopy interception, soil moisture dynamics,
and identification of flow pathways mechanisms for streamflow generation is ongoing in the
watersheds. It is necessary to continue the hydrologic monitoring of the ecosystem since it is
of great importance to quantify the effects of forest management on water supply and
determine the necessary balance between the production efficiency of this service and
365 ecosystem resilience.

The path to ecosystem management: bridging the gap between scientists and stakeholders

Science is informative about where one needs to do conservation, but silent on how to achieve
it (Knight et al 2006). There is a considerable gap between environmental sciences and the

370 design and execution of conservation projects in the field, and science is failing to inform the
practice of conservation. Linkages between science and management offer the potential to
bring the fields of landscape ecology, conservation biology, and environmental management
closer together (Jones et al 2012). The growing recognition that biodiversity provides people
with values that go far beyond aesthetics, spirituality, or recreation to encompass a range of
375 ecosystem services means that the sustainability of cities, villages, and cultures is linked with
the sustainability of natural ecosystems. Experience in the real world indicates that models for
conducting conservation planning initiatives should explicitly complement a systematic
conservation assessment with activities that empower individuals and institutions and
explicitly aim to secure conservation action. It must be understood that protected areas are not
380 stand-alone isolates and the landscape surroundings contain threats to the biodiversity and
ecosystem services within the preserve (Wiens 2009). The model followed in Llancahue, has
included a multidisciplinary research team that has worked from the beginning with
stakeholders that include public and private institutions as well as the campesinos of the
Lomas del Sol community. This case study helps further our understanding of the multi-
385 dimensional aspects of managing native forests with local people for biodiversity, forest, and
water conservation (Moorman et al 2013). Complex ecological and social settings must be
managed with operational models that include stakeholder collaboration, land-use planning,
social learning, and action research (Knight et al 2006) with the ultimate aim of ensuring the
persistence of nature's biodiversity, resilience, and ecosystem services together with
390 sustainable stakeholder livelihoods.

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Figure captions

Figure 1. Región de los Ríos (Region of the Rivers) in south-central Chile and its land cover, including medium- to large-sized public and private protected areas.

540 Figure 2. Three-dimensional projection of the Llancahue watershed (center of the image) near the city of Valdivia. The land-use matrix is dominated by industrial plantations under intensive management, including large clearcuts.

Figure 3. Land cover of Llancahue according to broad classes of types of forest that dominate
545 the watershed. The map shows the nine small catchments under monitoring, and the areas that have been managed.

Figure 4. Zoning of Llancahue according to five classes of preferential use.

550 Figure 5. Water yield in a watershed dominated by second-growth forests dominated by *N. dombeyi* in Llancahue. Data from September 2011 through February 2013.

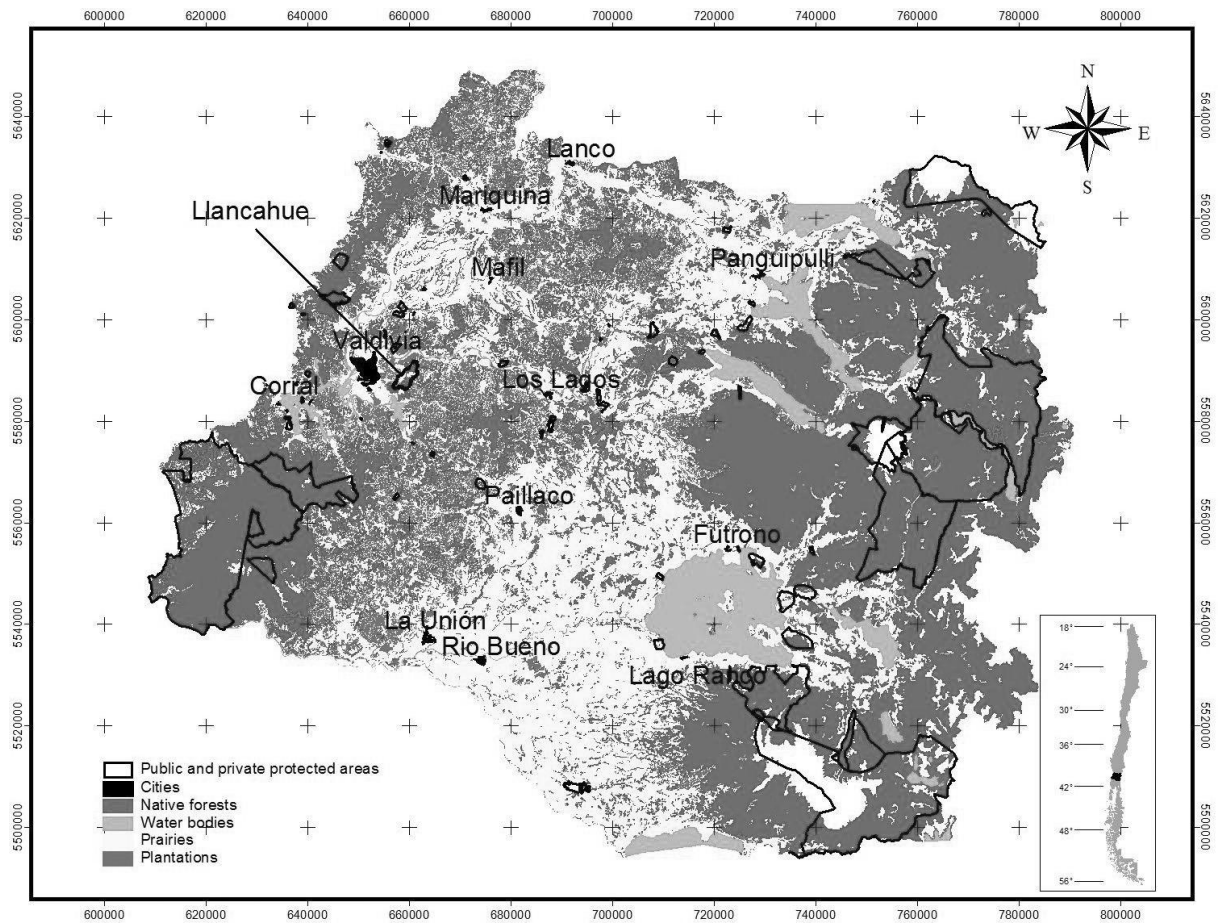


Figure 1.

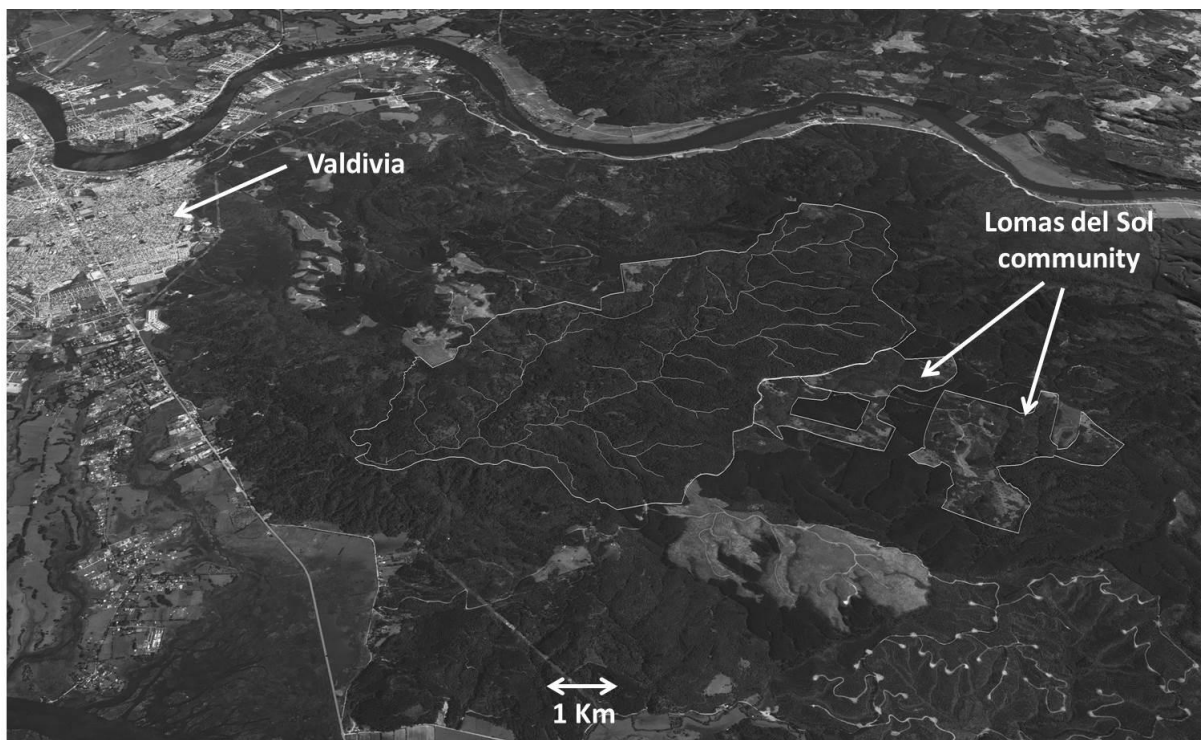


Figure 2.

Figure

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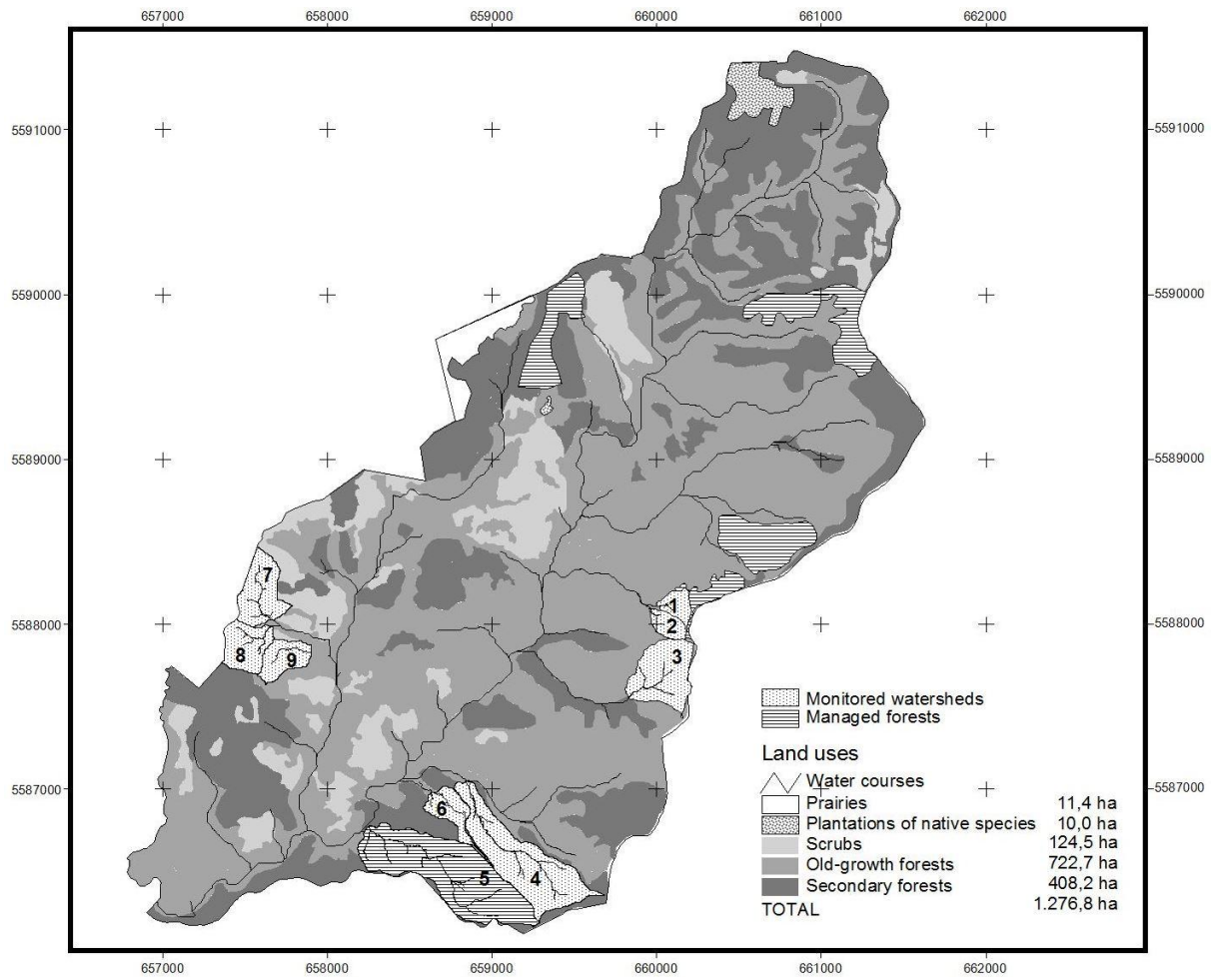


Figure 3.

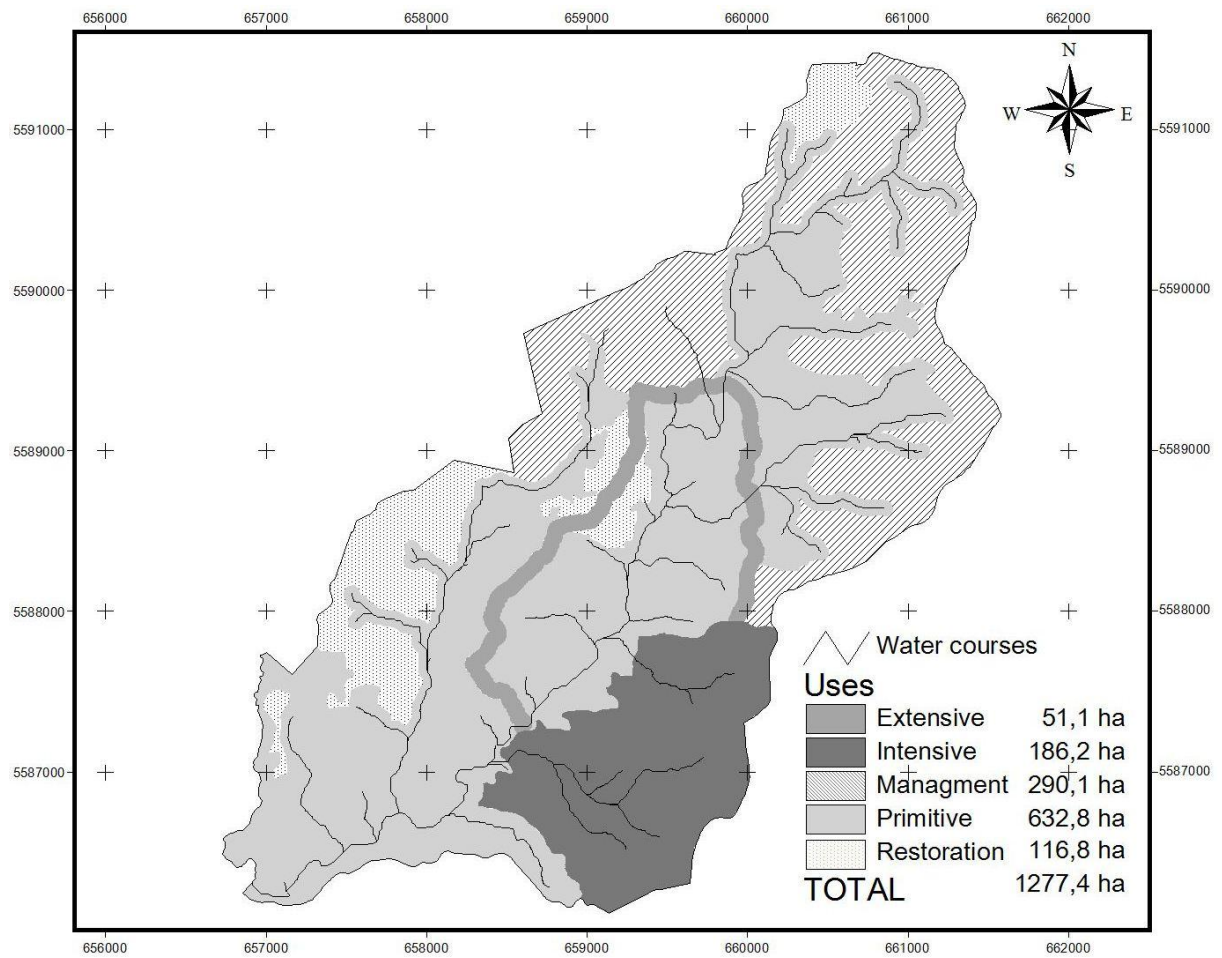


Figure 4.

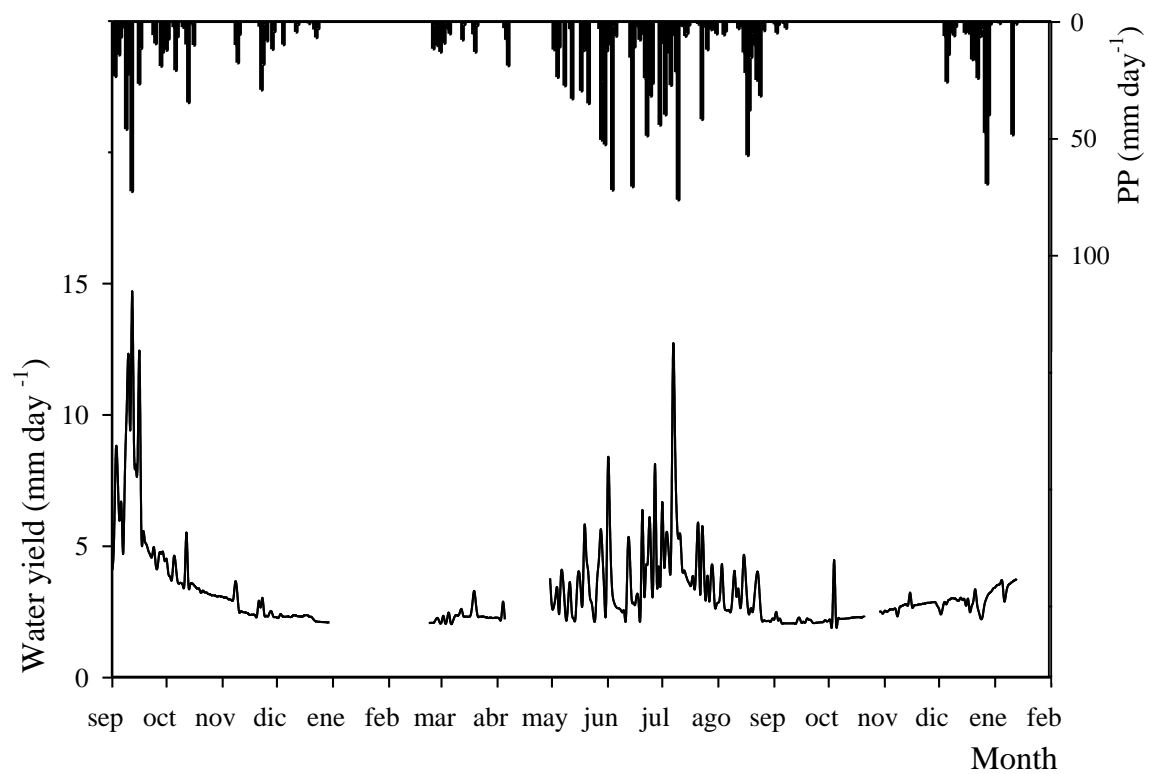


Figure 5.

Table 1. Expected old-growth attributes attainable through management (ST: short term <5 y; MT: middle term 5-10 y; LT: long term >10y) in different types of secondary forests in the Llancahue watershed.

Type of secondary forest	Stand variables			Expected old-growth attributes attainable through management			
	Tree composition	Vertical structure	Growth	Structural variables	Species compos.	Dead wood	Bird diversity
Mixed evergreen	Diverse (22 sps.)	Simple (one layer)	Very slow	LT	MT	MT	LT
<i>D. winteri</i>	Very simple (5 sps.)	Simple (one layer)	Interm.	LT	MT	MT	MT
<i>N. dombeyi</i>	Intermediate (10 sps.)	Complex (> 2 layers)	Fast	MT	ST	ST	ST

Table 2. Morphometric characterization of small watersheds under hydrologic monitoring. Watershed numbers correspond to those also reported in Figure 3.

Water- shed N°	Land cover	Area (ha)	Perimeter (m)	Average slope (%)	Channel length (m)	Average altitude (m a.s.l.)	Gravelius Index
1	Old-growth forest	2,8	848,5	15,4	265,2	336	1,43
2		2,8	707,0	17,6	303,6	335	1,19
3		12,7	1.562,2	25,2	639,1	316	1,24
4	Second-growth forests	23,2	2.968,2	25,0	1232,5	259	1,74
5		32,0	3.151,6	23,8	1561,1	220	1,57
6		5,2	1.921,0	17,4	787,2	191	2,38
7	Scrubs	9,2	1.642,8	36,8	478,2	259	1,53
8		7,3	1.297,0	36,1	579,4	278	1,35
9		5,5	1.261,3	35,1	581,3	243	1,52

Table 3. Socio-economic indicators of social intervention in Llancahue and its neighbor Lomas del Sol community.

Scope of intervention	Baseline (Ponce and Barrientos 2009)	Present (2013)
Llancahue watershed	<p>Illegal extraction using selective logging by 19 members of Lomas del Sol (15 families).</p> <p>Income undetermined, but estimated in USD 250/family/month</p>	<p>Forest management in Llancahue has incorporated 12 members of Lomas del Sol (9 families).</p> <p>Incomes estimated in USD 97/family/month plus USD 2700 community; Training in forestry practices</p>
Family farms	<p>One of 23 families has property title</p> <p>1 precarious structure for water supply (2 families); No irrigation systems</p> <p>Limited and precarious production of vegetables and poultry</p> <p>Inefficient coal production system</p> <p>90% of families with poor housing status</p> <p>No livestock management</p>	<p>95% of the families pending to legalize property titles</p> <p>7 structures for drinking water and irrigation and 4 water pump systems (14 families)</p> <p>7 greenhouses for vegetables; 8 henhouses; Training in greenhouses and orchard management for production of berries</p> <p>5 brick kilns and training to improve efficiency of coal production</p> <p>75% of families with poor housing status</p> <p>2 veterinarian visits per year to improve the health of livestock</p> <p>Training in first aid for domestic</p>

animals

Territory	Restricted access in winter due to bad road condition; Lack of electricity	All-year access through a gravel road developed by local government; Lack of electricity, but 95% of families enrolled in rural electrification committee
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Table 4. Comparison of some main density, composition and structural variables in second- and old-growth forest of Llancahue. In parenthesis standard deviation is shown for trees and basal area per ha as well for % trees >80% cm, and range for the Gini coefficient.

Forest	Trees per ha	Basal area (m ² ha ⁻¹)	Tree richness*				% trees >80 cm	Gini coefficient**
			St	It	Si	Tot		
Evergreen	1159	96,50	5	4	7	16	4,1	0.81
old-growth	(151)	(15.1)					(2.14)	(0.79-0.83)
<i>N. dombeyi</i>	1430	95,30	4	4	5	13	1.8	0.78
old-growth	(338)	(4.0)					(1.05)	(0.75-0.79)
<i>N. dombeyi</i>	1586	67.0	6	10	8	24	0.49	0.63
secondary	(366)	(18.5)					(0.07)	(0.58-0.75)
Mixed	4671	60.1	9	9	6	24	0	0.51
secondary	(717)	(7.9)						(0.48-0.60)
<i>D. winteri</i>	2880	69.5	6	7	5	18	0.69	0.58
secondary	(743)	(19.4)					(0.03)	(0.52-0.84)

* Tree richness is total number of tree species by shade tolerance (St: shade tolerant; It: intermediate tolerance; Si: Shade intolerant); Gini coefficient: ** mean value with range among plots in parenthesis.

Table 5. Mean dasometric characteristics (per-ha values) of the three secondary forests in Llancahue, and harvested volumes (per ha) of fuelwood (main product) including costs (incomes for campesinos) and the income generated per ha (in USD).

Forest/treat- ment	Trees		Basal area		QSD* (cm)	Relative density		Fuelwood harvested (m)	Cost of fuelwood (m)	Price of fuelwood (m)	Net income per ha
	Total	Main sps.	Total	Main sps.		Orig.	Resid.				
Mixed											
Crown	4914	1255	54,57	9.06	11.9	85	55	57	12	26	798
Ecological	4777	1018	57,47	6.03	12.4	88	56	55	12	26	770
Control	4671	1299	60,1	7.06	13,3	88	88				
<i>D. winteri</i>											
Crown	2560	1340	61	20.6	17.3	64	56	44	10	24	616
Ecological	2807	1860	70,77	34.8	17.9	74	53	154	10	24	2156
Control	2880	2100	69,5	38.9	18.9	72	72				
<i>N. dombeyi</i>											
Crown	1343	367	60,73	45.8	24.4	72	59	57	10	24	798
Ecological	1754	440	80,57	57.1	24.5	95	49	74	10	24	1036
Control	1802	429	71,83	53.7	23.0	87	87				