



Biodiversity and ecological long-term plots in Southern Patagonia to support sustainable land management: The case of PEBANPA network



Pablo Luis Peri^{a,b,c,*}, María Vanessa Lencinas^d, Jeffrey Bousson^e, Romina Lasagno^a, Rosina Soler^d, Héctor Bahamonde^{a,b}, Guillermo Martínez Pastur^d

^a Instituto Nacional de Tecnología Agropecuaria (INTA), CC 332 (9400) Río Gallegos, Santa Cruz, Argentina

^b Universidad Nacional de la Patagonia Austral (UNPA) Río Gallegos, Santa Cruz, Argentina

^c Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) Buenos Aires, Argentina

^d Centro Austral de Investigaciones Científicas (CADIC) Ushuaia, Tierra del Fuego, Argentina

^e Climate Science and Solutions Professional Science Master's Program, Northern Arizona University, S San Francisco Street, Flagstaff, AZ, 86001, USA

ARTICLE INFO

Article history:

Received 26 May 2016

Received in revised form

13 September 2016

Accepted 13 September 2016

Keywords:

Biodiversity

Carbon sequestration

Ecosystem services

Land use practices

Livestock grazing

Long-term monitoring

ABSTRACT

Historically, interactions and trends between biodiversity, ecosystem function (EF) and land use practices in southern Patagonia (Argentina) have been largely undocumented and poorly understood. Since 2002, 1214 permanent and semi-permanent plots within the PEBANPA Network have enabled researchers to monitor and assess functions and trends among vegetation parameters, biodiversity, forest dynamics, soil physicochemical characteristics, and land use management. The objectives of this manuscript are to communicate the role and rationale of the PEBANPA Network, summarize examples of the main results found within the network and provide guidance to decision makers with respect to advancing sustainable land management in southern Patagonia. As examples, rangeland health indices, seedling and sapling regeneration under different timber managed forests, litterfall and seeds production under silvopastoral use, and soil carbon content impacted by livestock grazing have all been assessed. Vegetation and environmental variables including soil respiration, soil water infiltration, soil water retention capacity, soil erosion, and litter cover were measured under different grazing intensities. Livestock and forestry production have caused changes in the original floristic patterns, with several areas experiencing desertification. Heavy stocking rates have caused the greatest impacts on grassland soil carbon (C) loss as a consequence of soil erosion. We were able to conclude that low – medium grazing intensities yield the most positive impacts for biodiversity and soil physicochemical characteristics. Studies regarding levels of seedling and sapling regeneration post-harvest of timber further supported the importance of long-term monitoring due to the strongest evidence of interactions occurring 20 to 30 years after harvest. Distribution patterns of vascular plants and epigeic coleopterons diversity revealed statistically significant differences among geographical zones and dominant vegetation types. The PEBANPA Network helps southern Patagonia address the challenges of unsustainable land management and climate change through monitoring ecosystem function and services. Long-term monitoring of biodiversity and ecosystem function help decision makers better understand the impacts of land use practices, develop well-informed policies and secure present and future human well-being.

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1. Introduction

Southern Patagonia (Argentina) is home to one of the few remaining well-conserved wilderness areas on the planet and where *Nothofagus* forests represent the southernmost forested ecosystem in the world. Internationally renowned for its moun-

tain landscapes, glaciers, arid plateaus, and diverse wildlife, some ecosystem modification and degradation has occurred in Patagonia due to human-induced influences such as forest harvesting, livestock production and the introduction of invasive, exotic species. The inaccurate assessment of the region's carrying capacity in relation to unsustainable land use practices has contributed to the alteration and modification of the region's original ecosystem structure. Silvopastoral systems, which incorporate grasslands or pastures and trees for livestock grazing in the same land area has become an ecological, economic and social land use practice alternative for the region (Peri, Bahamonde, et al., 2016). However, the

* Corresponding author at: Instituto Nacional de Tecnología Agropecuaria (INTA), CC 332 (9400) Río Gallegos, Santa Cruz, Argentina.

E-mail address: peri.pablo@inta.gob.ar (P.L. Peri).

majority of ranchers have been slow to adopt silvopastoral systems possibly due to lack of convincing evidence of positive economic returns or benefits from ecosystem services (ES) (Peri, Bahamonde, et al., 2016). The functions and interactions between ecosystem services and land management practices have been poorly understood within the region due to the lack of long term monitoring and research (Lindenmayer et al., 2012).

Provisioning and cultural ES within the region have historically provided economic benefits for local populations. Since the late 1880s, the production of ecosystem goods and services including timber extraction, livestock grazing (cattle and sheep), mining, and tourism have all further contributed to the region's economy. The region's forests have produced food, timber, fuel wood, and industrial products while livestock production has yielded meat, wool, leather, and dairy products. As a result of these production activities surpassing the ecosystem's natural carrying capacity, particularly during the period after European colonization, land degradation and biodiversity loss have recently occurred in Patagonia.

Throughout human history, societies have directly and indirectly benefited from ES; not only from provisioning and cultural, but also from regulating and supporting components. However, modern Western society has often taken ES for granted (Daily 1997; MEA, 2005) without considering the synergies and trade-offs between conservation and economic development as natural landscapes experience further degradation (Levin & Lubchenco 2008; Seppelt, Dormann, Eppink, Lautenbach, & Schmidt, 2011; Vitousek, Mooney, Lubchenko, 1997). Historically, economic markets have largely focused on the provisioning services (forest products, livestock, etc.) of ecosystems while neglecting the interdependent roles and regressing conditions of regulating services (erosion and climate control), supporting services (nutrient cycling), and cultural services (recreation, local identity, tourism) (MEA 2005). Since regulating, supporting and cultural services are often not considered during the development of land management practices (Kinzig et al., 2011), biodiversity and habitat health have either declined or are at-risk of degradation (Myers, 1997; Daily et al., 1997; Nahuelhual et al., 2007). Biodiversity loss threatens the health of each ES category, therefore placing present and future human well-being at-risk (Díaz, Fargione, Chapin, & Tilman, 2006; Felipe-Lucia & Comín 2015; Meli, Rey Benayas, Balvanera, & Martínez Ramos, 2014).

Long-term monitoring of all ES categories is required in order to better understand the functions and uses of each ES category (Boyd & Banzhaf, 2007; Fisher, Turner, & Morling, 2009). Developing and implementing sustainable land management strategies that consider future human well-being requires the analysis of synergies and trade-offs between biodiversity and ES provision (Tallis, Kareiva, Marvier, & Chang, 2008). Analyzing thresholds and trends for each ES category assists in identifying the optimal allocation of different land management practices at the landscape scale in Patagonia (de Groot, Alkemade, Braat, Hein, & Willemen, 2010). The intended analysis and consideration of trade-off decisions between ES and biodiversity can support effective conservation policies (Cordingley, Newton, Rose, Clarke, & Bullock, 2016; McShane et al., 2011) and advance multifunctional landscapes such as agro-forestry-environmental practices. Furthermore, scientific monitoring can help stakeholders understand the trade-offs and spatial flows of different services, sustainable use of ES and the economic feedbacks within ES markets (Tallis et al., 2008). Consideration of natural capital and ecosystem health extends well beyond conservation issues and is equally important for decisions related to agriculture, energy, water security, health, and national security (Guerry et al., 2015).

According to climate models, mean maximum annual temperature is predicted to increase by 2 to 3 °C by 2080 in the latitudinal range of 46° and 52° S (Kreps, Pastur, & Peri, 2012), therefore pre-

sending additional challenges for the future. The projected changes in climatic variables will most likely have profound effects on ES, biodiversity and land use capacity throughout the globe, including Patagonia. Unsustainable land management and global climate change present long-term threats and risks to human well-being and local ecosystems, therefore necessitating changes in land-use management practices and policies (IPCC, 2007).

The two traditional provisioning ES in Patagonia involve livestock grazing and wood harvesting (Peri, Hansen, et al., 2016) supported by grasses, forbs, shrubs and trees found within the habitats and lands of Patagonia. Since the relationship between ES and biodiversity is poorly understood and documented (Martínez Pastur, Peri, Lencinas, García Llorente, & Martín López, 2016) in Patagonia due to lack of successful research, the establishment of long term monitoring and studies are required. Hundreds of forest research programs with permanent forest plots had been initiated in the 1950s and 1960s as a response to forest mismanagement in Argentina. The main objectives of past long term monitoring programs was to transition old-growth forests into normal-stage managed forests. The result of these initial long-term studies was a failure due to a combination of factors: (i) absence of land management planning by national and provincial governments; (ii) insufficient contribution and collaboration from the private sector; (iii) lack of societal interest in environmental conservation and long-term forest research; (iv) unwillingness of scientific and forest research institutions to finance long-term forest studies; and, (v) fragmented and fractured implementation and responsibility between several different scientific researchers. It is important to learn from these past mistakes in order to implement a successful and effective long-term ecological research program.

In 2002, the PEBANPA (Parcelas de Ecología y Biodiversidad de Ambientes Naturales en Patagonia Austral) Network was established to monitor these ecosystems and to produce scientific research focused on ecosystem function and ES (e.g. soil carbon stocks, nutrients, forestry), as well as on trends in biodiversity and the interactions between natural environments and land-use activities throughout southern Patagonia, Argentina. Long-term monitoring assesses bio-indicators, which therefore reveal the current state of the environment, particular stresses in ecosystems and early warnings of environmental changes ahead.

The present network of long-term ecological monitoring plots alone cannot achieve sustainable land management practices without sustained financial commitment and cooperation from research, administrative and forest entities to maintain these research platforms. If developed, supported and implemented correctly, these long term plots in Patagonia will foster a better understanding and provide effective decision making tools necessary for advancing sustainable land management objectives and addressing regional socio-economic-ecological challenges.

The objectives of this manuscript are to: (i) communicate the rationale of the PEBANPA Network; (ii) provide a brief description of the main results and methodologies applied regarding the recent trends of biodiversity, forest dynamics, soil carbon content, and land-use practices documented within the region; and, (iii) include guidance for decision makers and stakeholders with respect to advancing sustainable land-use practices across Patagonia.

2. Materials and methods

2.1. PEBANPA network: role and characterization

The PEBANPA Network was developed in Argentina by the National University of Southern Patagonia (UNPA), the National Agricultural Technology Institute (INTA) and the Southern Center for Scientific Research (CADIC), which is part of the National Sci-

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