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Commentary

Progress in creating a joint research agenda that allows networked long-term socio-ecological research in southern South America: Addressing crucial technological and human capacity gaps limiting its application in Chile and Argentina

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Abstract Since 1980, more than 40 countries have implemented long-term ecological research (LTER) programs, which have shown their power to affect advances in basic science to understand the natural world at meaningful temporal and spatial scales and also help link research with socially relevant outcomes. Recently, a disciplinary paradigmatic shift has integrated the human dimensions of ecosystems, leading to a long-term socio-ecological research (LTSER) framework to address the world's current environmental challenges. A global gap in LTER/LTSER only exists in the latitudinal range of 40–60°S, corresponding to Argentina and Chile's temperate/sub-Antarctic biome. A team of Chilean, Argentine and US researchers has participated in an ongoing dialogue to define not only conceptual, but also practical barriers limiting LTER/LTSER in southern South America. We have found a number of existing long-term research sites and platforms throughout the region, but at the same time it has been concluded an agenda is needed to create and implement further training courses for students, postdoctoral fellows and young scientists, particularly in the areas of data and information management systems. Since LTER/LTSER efforts in Chile and Argentina are incipient, instituting such courses now will enhance human and technical capacity of the natural science and resource community to improve the collection, storage, analysis and dissemination of information in emerging LTER/LTSER platforms. In turn, having this capacity, as well as the ongoing formalization of LTER/LTSER programs at national levels, will allow the

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enhancement of crucial collaborations and comparisons between long-term research programs within the region and between hemispheres and continents. For Spanish version of the entire article, see Online Supporting Information (Appendix S1).

Key words: environmental monitoring, information management, long-term ecological research, LTER, LTSER, science policy, socio-ecology.

Resumen Desde 1980, más de cuarenta países han implementado programas de Investigación Ecológica a Largo Plazo (LTER por sus siglas en inglés), los cuales han mostrado su capacidad para influir sobre los avances en las ciencias básicas que permiten entender el mundo natural en escalas temporales y espaciales significativas, y también ayudar a enfocar la investigación hacia estudios socialmente relevantes. Recientemente, gracias a un cambio de paradigma en la disciplina, se integró también la dimensión humana de los ecosistemas, llevándola a un marco conceptual de Investigación Socio-Ecológica a Largo Plazo (LTSER por sus siglas en inglés) para enfrentar los desafíos medio-ambientales del mundo actual. Existe un vacío global en *LTER*/*LTSER* en el rango latitudinal de 40–60°S, correspondiente a los biomas templados/subantárticos de Argentina y Chile. Un equipo de investigadores chilenos, argentinos y estadounidenses ha trabajado por varios años para definir cuáles son la barreras que actualmente limitan la creación de una Red de *LTER*/*LTSER* en el sur de Sudamérica, no solamente en términos conceptuales, sino también a nivel práctico. Existe un buen número de sitios de investigación a largo plazo en la región, pero también concluimos que es necesario crear e implementar más cursos de capacitación para estudiantes, investigadores post-doctorales y jóvenes científicos, particularmente en las áreas de sistemas de manejo de datos e información. Considerando que los esfuerzos *LTER*/*LTSER* en Chile y Argentina son incipientes, este tipo de cursos podría mejorar la capacidad humana y técnica en la comunidad de las ciencias y los recursos naturales, así como mejorar los procesos de recolección, almacenamiento, análisis y difusión de la información. A su vez, la formalización de cursos de programas LTER/LTSER a nivel nacional para adquirir dicha capacidad de manejo de la información, permitirá un fortalecimiento crucial de las colaboraciones y comparaciones entre programas de investigación a largo plazo dentro de la región, y entre hemisferios y continentes. La versión en castellano del artículo se encuentra disponible en forma digital como Online Supporting Information S1.

Palabras clave: investigación ecológica a largo plazo, *LTER*, *LTSER*, monitoreo medioambiental, política científica, socio-ecología.

INTRODUCTION

Since its formal creation in 1980 as a program within the US National Science Foundation, long-term ecological research (LTER) has established itself as a framework for conducting science and developing institutional structures throughout the world. This framework permits the development of hypothesis-based questions that seek to reveal the structure and function of the biosphere at the spatial and temporal scales in which meaningful ecological phenomena occur (Callahan 1984). At the same time, continuous monitoring programs for a range of environmental variables also have provided the baseline necessary to generate scientific advances and necessary ecological information for decision making (Lovett *et al.* 2007; Likens & Lindenmeyer 2011). Given the relevance of this approach, between 1980 and 2010, more than 40 countries formalized national long-term ecological research platforms as part of the International LTER Network (ILTER; Parr 2010). Since its establishment and in various politico-economic contexts on all continents, LTER strategies have shown their utility as a basis for understanding the natural world (Franklin *et al.* 1990; Maass *et al.* 2010). Furthermore, during the last decade of the 20th century, it became increasingly necessary to broaden the LTER perspective by explicitly including the study of the human and social dimensions of ecosystems (Hobbie *et al.* 2003). This in turn provoked a change not only in name but in the overarching paradigm that organizes the scientific questions that are being asked and the ways we study them under the rubric of long-term socio-ecological research (LTSER *sensu* Haberl *et al.* 2006; see also Anderson *et al.* 2008; Collins *et al.* 2011).

Within the global research and monitoring network represented by ILTER, there has been a conspicuous historical absence of formal LTER/LTSER programs and sites in only one latitudinal range – 40–60°S, which corresponds to the temperate/sub-Antarctic biome shared between Chile and Argentina (Rozzi *et al.* in press). In contrast, we find numerous well-established LTER/LTSER programs at similar latitudes in the USA (e.g. H.G. Andrews Forest, Oregon; Bonanza Creek, Alaska), Europe (e.g. Scotland, Finland) and in some parts of the southern hemi-

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sphere (e.g. South Africa, Australia). As a result, the absence of formal efforts of complementary research in the southern part of South America is a significant limitation to potential collaborations between the northern and southern hemispheres, despite being bioclimatic 'mirror' sites (see Alaback 1991; Lawford *et al.* 1996; Veblen *et al.* 2002), and additionally it has been found in some cases the patterns observed in the northern hemisphere cannot be simply applied to the south hemisphere (Patterson 2010).

Here, we report the fundamental arguments that have been debated and conclusions that have been achieved by the authors in a series of workshops and meetings about long-term research, which culminated most recently in a symposium organized at the IV Binational (Chile–Argentina) Ecology Meeting, held from 8 to 13 August 2010 in Buenos Aires, Argentina. While Chile and Argentina are recognized as leaders in the ecological sciences in South America, during these workshops it was concluded that the community of ecologists and environmental science researchers still has a limited understanding of the technological and infrastructure goals and needs, as well as the academic and social benefits associated with LTER/LTSER programs. As such, there is currently insufficient awareness regarding the potential for these programs to serve as tools to advance ecological science and also develop sound public policies regarding environmental issues. On the other hand, since the 1990s, the community of ecologists in Chile and Argentina has manifested its concern about this lack of geographic representation of LTER/LTSER in the southern hemisphere (see Armesto 1990, 1995; Austin 2009; Anderson *et al.* 2010). Yet, historically there has been little support or coordination at the national and regional level to consolidate such research programs (Lara *et al.* 2010), in spite of the fact that here we identify a considerable number of cases of long-term research that are *de facto* or potential LTER/LTSERs dispersed throughout southern South America (see Table 1 for summary and Appendix S2 as Online Supporting Information for greater detail). Several of these long-term ecological research intiatives are additionally working at the conceptual vanguard of transition towards the LTSER paradigm by integrating ecological and social dimensions of ecosystems (Anderson *et al.* 2008, 2010). Furthermore, some of these initiatives are working to fulfil the objective of also imbuing basic research with socially relevant questions and results, such as research in marine management and conservation areas (Navarrete *et al.* 2010) and the provision of ecosystem services at the level of watersheds (Little & Lara 2010).

Consequently, the participants of the symposium organized in the binational meeting in Buenos Aires, including representatives of working groups from Chile, Argentina and the USA, arrived at the conclusion that the leading scientists and research centres should assume the responsibility of organizing the necessary steps to generate the conceptual, technological and human capacity that is required to define and also implement a consolidated and joint agenda between both Chile and Argentina for LTER/LTSER in the region, which subsequently could serve as a nexus between continents and hemispheres.

In this context, one of the immediate shortcomings we have detected to achieve these goals was the absence of capacity regarding information management systems and technologies within these emerging LTER/LTSER programs. Filling this gap is a necessary and essential component to advance in the process of consolidating networked, long-term research, but at the same time it is often not given due consideration (Franklin & Swanson 2010). Therefore, this aspect of LTER/LTSER should be highlighted and prioritized for implementation because information management provides the foundation for all further coordination of research collaborations within South America and between hemispheres, all of which requires data sets that are high quality, well documented and accessible. As a result, we recommend the generation of adequate technical and human capacity in information management as a fundamental step in the construction of an LTER/LTSER network, indeed constituting a next urgent step for research consolidation and coordination at a regional level.

EXISTING FOUNDATION FOR SUCCESS

It has become apparent that southern South America already has various existing long-term ecological research sites, some of which have more than five decades of data (Table 1), but many of these are not well known by the scientific community or authorities (see example in Martínez Pastur *et al.* 2010). To date, these pioneering LTER/LTSER initiatives in southern South America have shown the relevance of this approach to understand processes such as the effects of climate variability on populations and ecosystems. For example, 20 years of research in one of the largest vertebrate exclusion experiments in the southern hemisphere, found in the Fray Jorge Experimental Site in Chile, put into evidence the importance of El Niño Southern Oscillation (ENSO) events for determining the structure and function of these semi-arid ecosystems (Gutiérrez *et al.* 2010). In a similar way, the results of long-term monitoring and experimentation in the first marine protected area in Chile at Las Cruces Marine Station have had implications for the management of marine resources at a national level (Navarrete *et al.* 2010). On the other hand, long-term and large-scale experiments also exist to study changes in ecosystem services in the face of increasing exotic

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Table 1. General description of sites in Chile and Argentina that function as long-term ecological (or socio-ecological) research sites with more than a decade of work and at least minimum human and physical infrastructure to maintain current projects and programs (greater detail on funding and institutional arrangements can be found in Appendix S2)

Biome	Site name	Latitude °S Longitude °O	Year began	Principal ecosystems	References
Chile					
Mediterranean Zone	Fray Jorge Experimental Site	30°38′ 71°40′	1989	Arid shrublands with herbaceous strata	Gutiérrez *et al.* 2010
	Aucó Site	31°30′ 71°06′	1987	Arid shrublands with herbaceous strata	Jaksic *et al.* 1992
	San Carlos de Apoquindo Mediterranean Ecological Research Station	33°30′ 70°30′	1976	Shrublands and sclerophyllous forests	Jaksic 2001
	Las Cruces Coastal Marine Research Station	33°30′ 71°38′	1982	Rocky coast and inter-and sub-tidal zones	Navarrete *et al.* 2010
Valdivian Rainforest Zone	San Pablo de Tregua Station	39°36′ 72°06′	2004	Old-growth and secondary forest Mixed and evergreen *Nothofagus* forest	Lara *et al.* 2009
	San Martín Station	39°38′ 73°07′	1982	Mixed and evergreen secondary forest, wetland forests dominated by Myrtaceae	Muñoz and González 2009
	Valdivian Coastal Reserve Station	39°58′ 73°35′	2005	Old-growth and secondary forests, mixed and evergreen forest, exotic plantations	Little and Lara 2010
	Senda Darwin Biological Station	42°53′ 73°39′	1995	Valdivian and north Patagonian forest, bogs, shrublands, river and riparian zone	Carmona *et al.* 2010
Sub-Antarctic Zone	Omora Ethnobotanical Park	54°57′ 67°39′	2000	Sub-Antarctic forests, peat bogs, marine channels	Rozzi *et al.* 2010
Antarctic Zone	Shirreff Cape & San Telmo Islets	62°27′ 60°47′	1985	Island and marine coast	Torres 1985
Argentina					
North Patagonia Zone	Puerto Blest Biological Station	41°01′ 71°93′	2005	Valdivian forest	Sanguinetti and Kitzberger 2008
	Pilcaniyeu Experimental Field	40°75′ 70°49′	2000	Patagonian steppe	Nosetto *et al.* 2006
South Patagonia & Sub-Antarctic Zone	San Martin Forestry Station	42°18′ 71°17′	1998	Sub-Antarctic forest of cordilleran cypress	Licata *et al.* 2008
	Southern Patagonia	51°13′ 72°15′	1993–2010	Sub-Antarctic *Nothofagus* forest	Martínez Pastur *et al.* 2010

forest plantations in south-central Chile, which affect such services as the maintenance of biodiversity (Echeverría *et al.* 2006) and the provision of water quality and quantity (Oyarzún *et al.* 2007; Little *et al.* 2008; 2009; Lara *et al.* 2009). Also, some newer programs in Chile, established since the Sustainable Biosphere Initiative of the Ecological Society of America (Lubchenco *et al.* 1991), have been more likely to include novel approaches to the inclusion of social topics to transform sites into LTSER. For example, there have been efforts to focus on the integration of interdisciplinary research, education and outreach (e.g. Senda Darwin Biological Station), as well as an initiative to integrate the sciences and

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humanities (e.g. Omora Ethnobotanical Park) (Anderson *et al.* 2008).

For its part, in Argentina, we also find various research programs coexisting, many of which are focused on processes that occur at multi-year and decadal time scales. For instance, long-term studies of the effect of drought on *Nothofagus* forests have demonstrated that the vulnerability and mortality of trees to severe droughts is partially explained by their relationship with previous drought events (Suárez *et al.* 2004). Joined with this, it has been shown that fire, as a consequence of human activity, is important to define the limits of the ecotone between the forest and more arid vegetation cover (Veblen *et al.* 1996). In this way, the dual role of the legacy effects of climate and fire over the dynamics of forests appears to be a crucial factor that affects long-term regeneration and persistence of temperate forests on the eastern slopes of the Andes in northern Patagonia. Similarly, long-term monitoring of insect herbivory in sub-alpine *Nothofagus* forests has permitted us to understand the role of extreme climate events in the regulation of trophic interactions in the canopy (Mazía *et al.* 2004; 2009). Another ecological phenomenon that required discernment of long-term processes was the study of infrequent flowering events for understory bamboo (*Chusquea culeou*), events which occur at more than 50 year intervals but that can impact trophic dynamics of herbivores and predator-prey relationships (Caccia *et al.* 2009), light conditions, ecosystem characteristics and forest regeneration (Austin & Marchesini 2011). Additionally, the disruption of interactions between trophic groups due to biological invasions has the potential to have long-term effects on the intensity of intraspecific relationships such as between leaf litter and decomposers (Vivanco & Austin 2011). Farther south we find long-term studies that have been more focused on silvicultural management strategies for southern Patagonian forests, searching to link biodiversity conservation with economic sustainability, including (i) traditional management practices such as shelterwood cuts and silvo-pastoral systems (Peri 2005) and (ii) new silvicultural proposals that include different levels of retention (aggregated and dispersed retention) (Martínez Pastur *et al.* 2010). It bears mentioning that there are a great variety of similar studies in the northern hemisphere (e.g. Aubry *et al.* 1999) and very few for comparison in the southern hemisphere (e.g. Martínez Pastur *et al.* 2010).

A JOINT AND IMMEDIATE WORKING AGENDA

In spite of this solid foundation, the continuation and linking of these *de facto* LTER/LTSER sites has been obstructed by the fact that, among other things, the community of ecologists in Chile and Argentina has scarce experience in the systematic management of information. As a result, one of the principal goals of the existing LTER/LTSER initiative partners in Chile and Argentina should be to develop not only the conceptual basis, but also the technical capacity to achieve networking. Doing so would permit the formal linking of these interdisciplinary data sets within national borders and also between countries and with climatically similar sites outside the region. Achieving this goal could improve the study of socio-ecological systems at high latitudes in both hemispheres and prepare us to address shared environmental challenges. This objective also coincides with that proposed by authorities in both hemispheres of the Americas, such as a recent editorial in *Science* that called for increased cooperation between countries of the Americas (DeVoogd 2010), and also coincides with current efforts to generate continental scale ecological science (Schimel 2011). With this goal in mind, we propose a training program with experts in the use of information technology and data management for long-term research as a way to: (i) strengthen the development of LTER/LTSER in Chile and Argentina through the sharing of state of the art methods and technology of information management for natural resources and environmental studies, and (ii) stimulate and institutionalize research alliances between LTER/LTSER sites in Chile and Argentina and with sites in other parts of the world particularly bioclimatically similar sites in North America (i.e. 'mirror' sites).

This focus on information systems and management should be developed based on fundamental conceptual themes and related to basic LTER/LTSER research questions, including, but not limited to: (i) the evaluation of biotic and abiotic controls over carbon flows in response to climate change and precipitation gradients, (ii) the impact of natural and human disturbances, such as changes in land use and the effects on water quantity and quality provisioning at multiple temporal and spatial scales, and (iii) social changes in rural and less disturbed landscapes, given the current rapid urban development and potential transformation of frontier ecosystems, which is information of potential use to decision makers. In particular, the envisioned course (or series of courses) could use as a central organizing theme an emphasis on biogeochemical functioning, given that this research focus permits taking advantage of the fact that these sites are found in the southern hemisphere, which in contrast to the North, are positioned as global control sites for comparison of nutrient cycling conditions before the Industrial Revolution (Perakis & Hedin 2002; Galloway *et al.* 2004).

For these reasons, we believe it is necessary to explore not only the use of LTER/LTSER in southern

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South America as a transformative approach to involve the scientific community at the regional and national levels, but also as a way to help build a bridge between disciplines and between science and society. All of these challenges require the establishment of the necessary technological foundation to share information that will permit future collaborations between sites and countries. The implementation of this agenda also could reduce the chance that the LTER/LTSER sites in Chile and Argentina have some of the significant and common problems that affect other such programs regarding the management, processing, distribution and storage of data, including issues regarding its availability, fidelity and meta-data content (Boose *et al.* 2007; Costello 2009).

Specifically, by taking steps to support the education and training of scientists and students about information systems and technology, it is hoped that a common agenda can be created with long-term impacts because it:

- will prepare graduate students, postdoctoral fellows and young scientists within the natural and environmental sciences to design, create and administer information systems that assure quality, distribution, accessibility and integration of common databases;
- will develop regional and international collaborations between young researchers within South America and between hemispheres;
- will permit the evaluation and contextualization of meta-data policies and standards used in other successful long-term ecological research programs as regards to how they can be applied to southern LTER/LTSER initiatives;
- will increase knowledge among Latin American scientists about the value and necessity of addressing long-term questions, as well as interdisciplinary proposals, utilizing the emerging networks of LTER/LTSER sites;
- will contribute to the capacity of participants to address specific questions that involve a wide spatial and temporal scale through the integration of advanced information technologies in LTER/LTSER;
- will establish the potential role of LTER/LTSER as a research platform that can address topics that link the social and natural sciences with the humanities, as well as academic institutions with society.

FINAL COMMENTARIES ON THE IMPORTANCE OF THIS AGENDA

In an era of human-induced global change that includes habitat fragmentation, climate change and the impacts of invasive species (Vitousek *et al.* 1997), the temperate and sub-Antarctic ecoregions of southern South America merit special attention; they exhibit singular attributes that make them relevant for long-term research. For example, along this latitudinal extension, we find a marked gradient of ecosystem variables including temperature, photoperiod, precipitation, degrees of disturbance, anthropogenic impacts, exposure to ultraviolet radiation, elevation, species assemblage and transitions between vegetation types (e.g. steppe and forest) (Lawford *et al.* 1996). Also, here we find the most extensive temperate forests in the southern hemisphere (Armesto *et al.* 1996; Veblen *et al.* 1996), having as well the largest temperate wetlands in the hemisphere (Arroyo *et al.* 2005) and the greatest continental ice fields outside of Antarctica and Greenland. Finally, this region is one of the few places on the planet that does not experience significant atmospheric deposition of nitrogen and other industrial contaminants, making it a global 'control' site for pre-Industrial Revolution biogeochemical cycles (Galloway *et al.* 2004). Taking into account these singularities, the establishment of a LTER/LTSER network in this biome of Chile and Argentina would provide an enormous opportunity for studies of these socio-ecological systems in southern South America and permit comparisons with other 'mirror' sites in the northern hemisphere and biogeographically similar sites in the southern hemisphere, such as those areas that were formerly part of Gondwana. The creation of such a network is a priority, not only as a research platform, but also as a paradigm that seeks to study the dynamics of the real world where human/nature systems are coupled at large spatial and temporal scales.

In the case of southern South America, efforts to consolidate LTER/LTSER are incipient. As a result, we find ourselves positioned at a unique moment to facilitate success through the planning of a process focused on establishing the principal questions that will be relevant to frame integrated socio-ecological research. In this context, we propose the introduction of information management and technology into the emerging paradigm of LTER/LTSER. We recommend the preparation of one or more workshops or training courses oriented towards graduate students, postdoctoral fellows and young scientists to achieve this goal. The integration of information management into LTER/LTSER in the extreme southern tip of the Americas at this stage will provide the basic technical and human capacity to allow the improvement of information collection, storage, analysis and dissemination, which is critical for long-term monitoring and research (Baker 2000). Addressing these challenges now and taking advantage of these time-sensitive opportunities should be considered urgent by the community of environmental scientists and science policy makers, as part of our efforts to understand, value, manage and conserve our socio-ecological systems.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Appendix S1. The Spanish version of this article is offered as Supporting Material Appendix S1: http://libproxy.library.unt.edu:2179/doi/10.1111/j.1442-9993.2011.02322.x/suppinfo.

Appendix S2. Detailed description in English and Spanish of the sites in Chile and Argentina that function as long-term ecological (or socio-ecological) research sites with more than a decade of work and minimum human and physical infrastructures to maintain current programs and projects.

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