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Alpine Ecology in the Iberian Peninsula: What Do We Know, and What Do We Need to Learn?

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The 11th Conference of the Spanish Association of Terrestrial Ecology, held in Pamplona, Spain, on 6–10 May 2013, included a symposium on alpine ecological research in the Iberian Peninsula. This session offered an excellent opportunity to assess the state and progress of alpine ecology in this region, identify knowledge gaps, and discuss further directions for research. Iberian alpine ecosystems are biodiversity hotspots and have traditionally contributed to sustaining rural livelihoods. Today, these ecosystems are subjected to large changes in land uses, including land abandonment, and are affected by climate change. This article reviews the current state of Iberian alpine ecology and proposes a research agenda. Alpine ecology in the Iberian Peninsula is a growing field of research. The need for larger spatial and temporal scales in research and monitoring, along with the integration of socioecological aspects, is a critical issue for understanding the major drivers of change in the alpine ecosystems of the Iberian Peninsula. The implementation of effective mitigation strategies aimed at reducing the impact of the pressing environmental and socioeconomic problems of Iberian mountain areas can only be accomplished through a multidisciplinary and integrative approach.

Keywords: *Alpine ecosystems; global change; mountain areas; socioecological research.*

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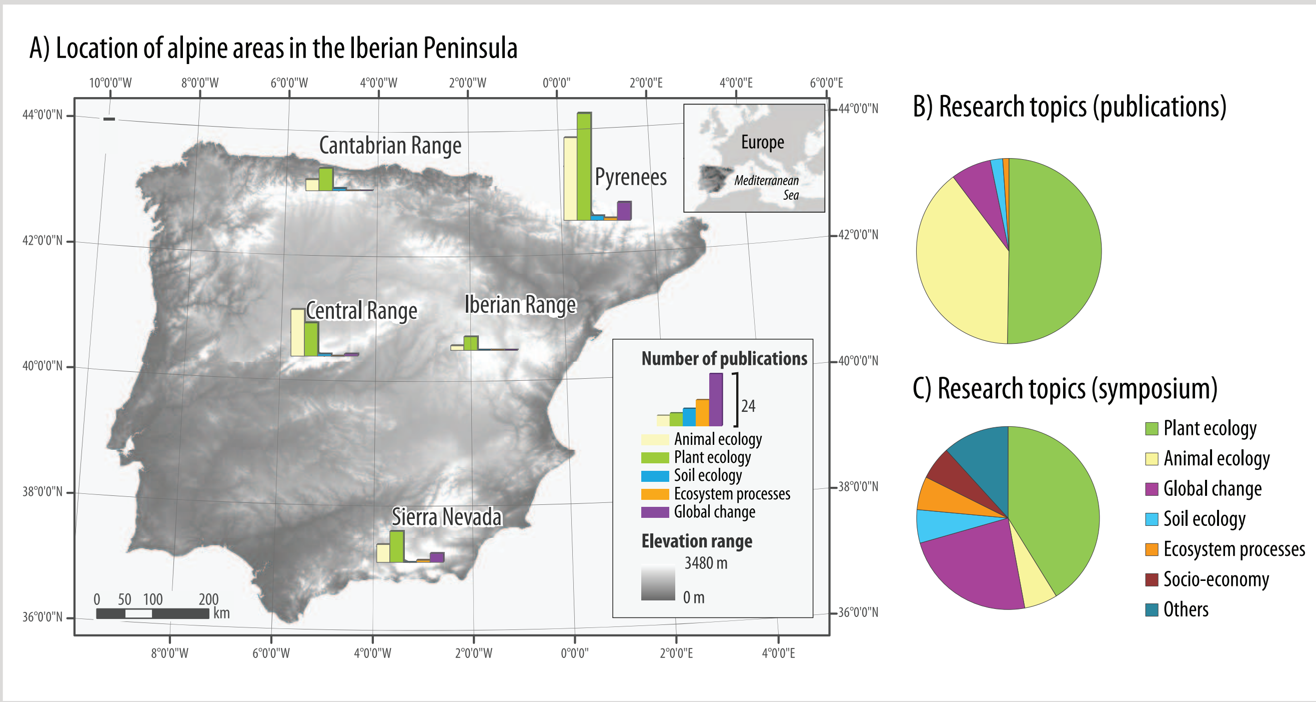
Introduction

The Iberian Peninsula has one of the most rugged landscapes in Europe, and its mountains host alpine ecosystems (understood broadly as ecosystems occurring above the tree line) of Euro-Siberian (Pyrenees and Cantabrian Range) and Mediterranean (Central and Iberian Ranges, as well as Sierra Nevada) biogeographic origin (Figure 1). Alpine ecosystems across the Iberian Peninsula are geographically isolated islands, which increases their scientific and conservation interest (Körner 2003). Like most mountains worldwide, they provide important ecosystem services that sustain rural livelihoods and are exposed to a range of stressors, including climatic, political, economic, and sociocultural forces (IPCC 2012).

Rural abandonment since the 1960s, as a consequence of the collapse of European rural economies (MacDonald et al 2000), has led to land use changes that have driven profound changes in Iberian mountains. Historically, traditional grazing activities and associated management practices have contributed to the diversity of Iberian alpine grasslands (Sebastià et al 2008), and tree lines have been locally lowered in elevation by pastoral use (Ninot et al 2008). However, the abandonment of traditional land uses has led to densification of the tree lines, recolonization of deforested areas (Batllori and Gutiérrez 2008; Améztegui et al 2010; García-Romero et al 2010), and shrub encroachment. This, coupled with intensive afforestation policies, has resulted in a drastic reduction in the extent of grasslands, an increase in large-scale fire hazards, and the loss of important ecosystem services such as water availability and landscape diversity (García-Ruíz and Lana-Renault 2011; WWF/Adena 2013).

Climatic warming is also expected to have a large impact on alpine habitats, and there is clear evidence of

FIGURE 1 Main alpine areas in the Iberian Peninsula and research on alpine ecology, 1977–2013. (A and B) The data source is Web of Knowledge (Thomson Reuters 2013); (C) The symposium is the symposium on alpine ecological research in the Iberian Peninsula held at the 11th AEET Conference, 6–10 May 2013. (Figure by Maite Gartzia)



this in the Iberian Peninsula. For instance, mean temperature has increased at an average rate of +0.3°C per decade between 1950 and 2006 in the Pyrenees (López-Moreno et al 2010); upward range extensions in species distribution in response to warming have been reported for different organisms including plants (Sanz-Elorza et al 2003), invertebrates (Wilson et al 2007), and vertebrates (Lurgi et al 2012). In the case of plants, changes in Iberian and other Mediterranean high mountains seem to be faster and more dramatic than in boreal–temperate European mountain ranges, because upslope shifts tend to decrease species richness (Pauli et al 2012). Mediterranean summer droughts pose an additional constraint to plant growth even in the alpine belt (García-Cervigón et al 2012), and altitudinal migration may not be a straightforward response to climate change as in other European mountains (Olano et al 2013).

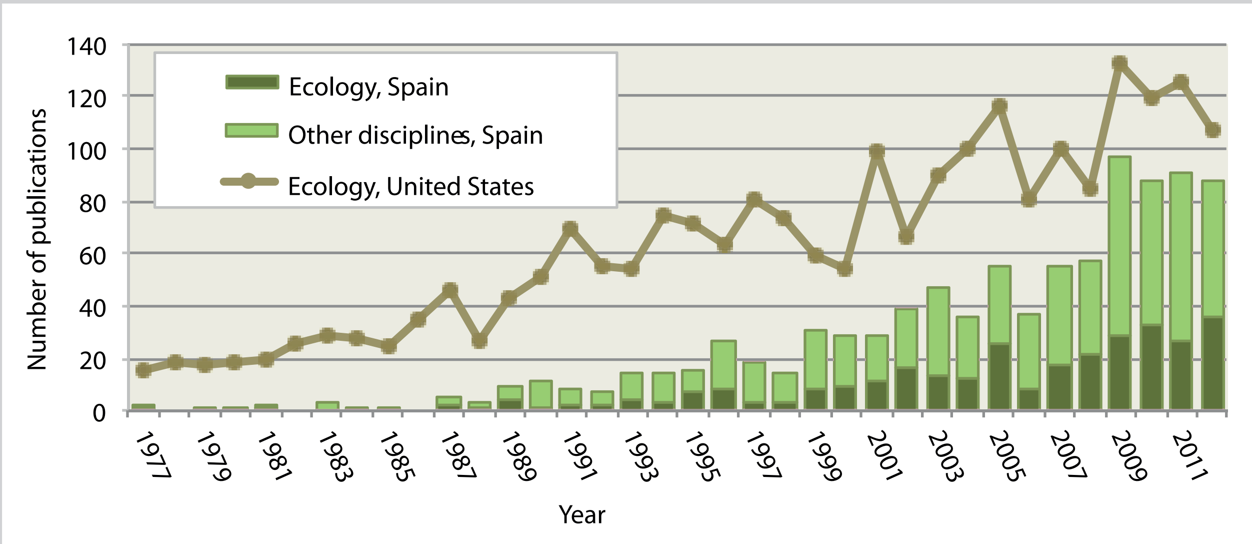
Alpine areas represent challenges to researchers, conservationists, and land managers. Some alpine ecosystems, such as snow beds, can serve as early indicators of change due to their marked sensitivity to external drivers (Nagy 2006). In turn, the rugged alpine terrain provides an opportunity for natural experiments, because sharp environmental gradients occur over relatively short distances (Scherrer and Körner 2011). Understanding the processes, mechanisms, and responses to external drivers can greatly expand our ability to preserve these ecosystems and promote the sustainable use of the services they provide. The 11th Conference of the Spanish Association of Terrestrial Ecology (AEET) represented a timely opportunity to chart the current state of alpine ecological research in the Iberian Peninsula. Based on the conclusions of the symposium, this article reviews pivotal issues and proposes a research agenda. Abstracts of the symposium are available at the AEET website (AEET 2013).

Alpine ecology in the Iberian Peninsula: what we know now

Iberian alpine systems have long attracted scientific interest. Early biological cataloguing and documentation have given way to more integrative approaches, such as studies on functional traits or ecosystem functioning (eg Illa et al 2006). Alpine research in the Iberian Peninsula has greatly increased in recent decades (Figure 2). A Web of Knowledge (Thomson Reuters 2013) search in May 2013 for the keywords “alpine” and “Spain” (following Körner 2009) returned 320 hits in environmental sciences and ecology, of which 154 were studies in terrestrial ecology. Most of the research was conducted in the Pyrenees (96), followed by the Central Range (38), Sierra Nevada (27), Cantabrian Range (16), and Iberian Range (8).

Discrepancies among geographical locations may partly reflect the different extents (and importance) of alpine habitats in each range, with those in the Pyrenees being the largest. Alternatively, they may indicate the positive impact of having a dedicated local research

FIGURE 2 Alpine research in Spain and the United States, 1977–2013. For Spain, ecological research on alpine areas is indicated by the darker bars. Other disciplines (lighter bars) range from biomedical sciences to geography. For the United States, the leading country for alpine publications (Körner 2009), only ecological research is shown (solid line). The data source is the Web of Knowledge (Thomson Reuters 2013). (Figure by Isabel C. Barrio)



institution focusing on alpine ecology. Most studies were conducted on a single mountain range, while 17 (11%) included comparisons with other ranges. The number of multisite comparisons has greatly increased in recent years, with 90% of these studies published since 2000. Studies mainly focused on plant and animal ecology (Figure 1), and none dealt with socioecology. Some such studies may have gone undetected in our search because they did not use the word "alpine." For instance, the term "mountain" might be more common in other disciplines (Körner 2009), but it would also encompass nonalpine habitats that are outside the scope of this paper. Our search did not cover the gray literature; nonetheless, we acknowledge that nonacademic publications make up an important body of work that often contains relevant development-oriented research on mountains and mountain communities.

Current research on alpine ecology in the Iberian Peninsula was presented at the AEET symposium in 17 talks, including 2 by invited speakers. Topics ranged from an overview of Iberian alpine research to the main drivers of vegetation change in Iberian mountains (Figure 1C). Global change was a hot topic, with emphasis on shrub encroachment. One of the central issues debated was the role of humans in the management and "preservation" (*sensu* Collins et al 2011) of alpine socioecological systems. Traditional knowledge of pastoralists can contribute to sustainable stewardship and provide strategies for adaptation in the face of changes (Fernández-Giménez and Fillat 2012), but social and ecological research in mountain systems are rarely integrated (Björnsen Gurung et al 2012). Recent initiatives are trying to integrate ecological monitoring with land use and policy aspects; 2 such examples are the proposed Global Change Observatories in Spanish Protected Areas (Zamora 2010), one of which is now operating in the Sierra Nevada (Observatorio Cambio Global Sierra Nevada 2013), and a pan-European study on land-use changes and the socioeconomy of mountains—Enhancing the Resilience Capacity of Sensitive Mountain Forest Ecosystems Under Environmental Change (COST 2012).

The way forward

The main directions for future research that emerged from the symposium fell into 4 broad areas.

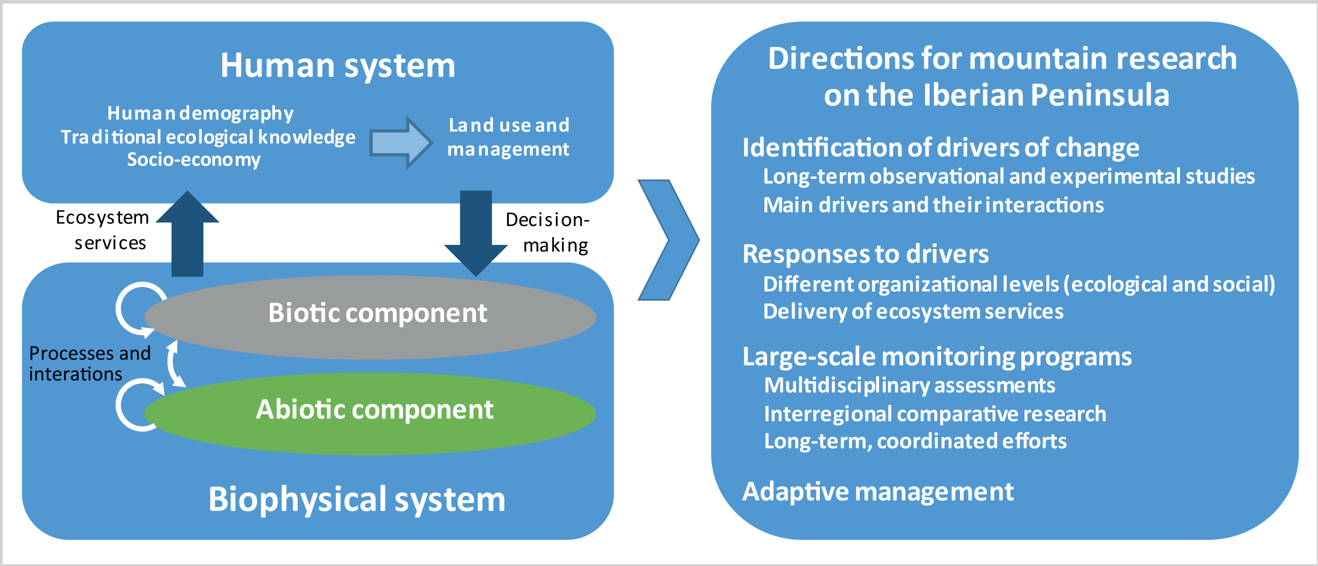
Identify the drivers of change

Understanding ongoing changes is critical to predicting future impacts. To identify the main causes of change, and distinguish their effects from natural variation, it is essential to establish baseline monitoring programs (discussed later) focusing on the main functional ecosystem processes. New, promising tools can help this goal; for example, herb chronology (von Arx et al 2012; Olano et al 2013) can provide a temporal perspective of the dynamic response of alpine ecosystems to environmental changes.

Most studies have investigated the effects of land abandonment and warming on alpine Iberia, but the impacts of other drivers, such as introduced and range-expanding species (eg Hódar et al 2012; Barrio et al 2013), need further exploration.

Potential interactions among drivers need to be considered as well. For example, shrub encroachment is mostly linked to the abandonment of traditional livestock practices, but the role of climate change and the interactions between the 2 drivers are less well understood (but see Sanz-Elorza et al 2003; García-Romero et al 2010). Research on drivers requires experimental designs, such as increasing the temperature of focal species using open-top chambers to forecast

FIGURE 3 Conceptual diagram of the functioning of alpine systems. Biophysical and human systems are closely related, highlighting the need to integrate all aspects in future research. (Figure by C. Guillermo Bueno)



responses at the population level or studying changes in the diversity and productivity of areas with a long grazing history after cattle exclusion.

Analyze the responses of individuals, populations, and ecosystems to external drivers

Responses at different organizational levels can determine how ecosystems react to impacts. For example, both local adaptation processes and dispersal or migration capacity might be relevant to the response of populations at their range limits. Knowledge on this adaptive potential would inform strategies that minimize the impact of global change on biodiversity.

Investigating how external drivers can affect the delivery of ecosystem services is paramount. The relationship between social and ecological systems is reciprocal (Collins et al 2011; Figure 3); decision-making by humans affects ecosystem processes, which in turn feed back to human well-being by determining the quality and quantity of ecosystem services. For example, human-related changes in the Pyrenees (eg demographic changes leading to rural abandonment and forest regeneration) are driving increases in populations of certain forest animals, like wild boars *(Sus scrofa)*. In turn, wild boars root up extensive areas while foraging in alpine grasslands (Bueno et al 2010); this is perceived by farmers as a reduction of the surface available to livestock grazing (one of the ecosystem services provided), and this drives further decision-making.

Develop larger-scale monitoring programs

While some initiatives have long been in place for specific taxonomic groups, such as the Global Observation Research Initiative in Alpine Environments for plants (Pauli et al 2012), efforts should also target multidisciplinary assessments in which socioecological aspects are considered. Ideally, these monitoring networks could build on ongoing initiatives and learn from experiences at other sites. A solid monitoring program should be aware of the past to understand the present and try to adapt to the future; this is particularly important in Mediterranean mountain ecosystems, which have been managed by humans for centuries.

Comparisons across mountain ranges and long-term data collection networks can provide useful insights into processes and responses to changes and can inform management practices (McDougall et al 2011). On a global scale, comparative long-term data and research can be achieved by forming a coordinated alpine environmental observatory network, such as the one within the Global Mountain Biodiversity Assessment (2013), which includes long-term ecosystem research (LTER) sites from areas with different climates and land use histories. The LTER-Spain network (2012) contains 3 important mountain nodes (Ordesa and Monte Perdido, Sierra Nevada, and Aigüestortes National Parks), where a basic collaboration is being developed to share protocols for data collection on land use changes, plant and animal population trends, and running-water analyses. Comparative research across time and space can validate the impacts of environmental factors on the functioning, vulnerability, and sustainability of natural and anthropogenic systems in alpine environments globally.

Implement adaptive management

Monitoring should guide management to reduce uncertainty, through an iterative process of robust decision-making, by accruing information that improves further management (Lindenmayer and Likens 2009). Mountain protected areas are invaluable as natural laboratories for adaptive management practice (eg Zamora 2010). The dynamic integration of stakeholders, policy-makers, researchers, and practitioners is indispensable (eg Ausden 2007); the recently established Global Change Observatory in the Sierra Nevada constitutes an example of such collaboration. Unfortunately, these pioneering initiatives now face a deep economic crisis, slowing the results of the hard work that has been done and hampering their spread to other mountain areas. Specifically, there is a clear need for interdisciplinary approaches that encompass socioecological aspects, because research on social systems in Iberian mountain areas (eg Moscoso 2006; Lasanta and Marín-Yaseli 2007) is generally not well integrated with ecological research (but see Fernández-Giménez and Fillat 2012).

Concluding remarks

Alpine ecology is a dynamic field of research in the Iberian Peninsula. Current and predicted changes, primarily in land use and, to a lesser extent, in climate and biotic exchanges, pose challenges to researchers, conservationists, and managers. Improving our understanding of the responses of individuals, populations, and ecosystems to global change will facilitate decision-making to mitigate ecological and socioeconomic impacts. However, this can only be achieved under a new conceptual framework, in which socioeconomic aspects are analyzed together with ecological processes, following adaptive management guidelines based on and developed from solid scientific knowledge. Due to Iberian mountains' long history of human use, their ecology cannot be isolated from past and present socioeconomic forces. Hence, it is time to build bridges across disciplines and to encourage researchers, stakeholders, practitioners, and policy-makers to work together toward sustainable development of Iberian mountains that provides for the conservation of their natural resources, the provisioning of their ecosystem services, and their socioeconomic profitability.

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REFERENCES

AEET [Spanish Association of Terrestrial Ecology]. 2013. Asociación Española de Ecología Terrestre [in Spanish]. http://www.aeet.org; accessed on 10 October 2013.
Améztegui A, Brotons L, Coll L. 2010. Land-use changes as major drivers of mountain pine (*Pinus uncinata* Ram.) expansion in the Pyrenees. *Global Ecology and Biogeography* 19:632–641.
Ausden M. 2007. *Habitat Management for Conservation.* Oxford, United Kingdom: Oxford University Press.
Barrio IC, Herrero J, Bueno CG, López BC, Aldezabal A, Campos-Arceiz A, García-González R. 2013. The successful introduction of the alpine marmot *Marmota marmota* in the Pyrenees, Iberian Peninsula, Western Europe. *Mammal Review* 43:142–155.
Batllori E, Gutiérrez E. 2008. Regional tree line dynamics in response to global change in the Pyrenees. *Journal of Ecology* 96:1275–1288.
Björnsen Gurung A, Wymann Von Dach S, Price MF, Aspinall R, Balsiger J, Baron JS, Sharma E, Greenwood G, Kohler T, Bjo A, Von Dach SW. 2012. Global change and the world's mountains—Research needs and emerging themes for sustainable development. *Mountain Research and Development* 32:S47–S54.
Bueno CG, Barrio IC, García-González R, Alados CL, Gómez-García D. 2010. Does wild boar rooting affect livestock grazing areas in alpine grasslands? *European Journal of Wildlife Research* 56:765–770.
Collins SL, Carpenter SR, Swinton SM, Orenstein DE, Childers DL, Gragson TL, Grimm NB, Grove M, Harlan SL, Kaye JP, Knapp AK, Kofinas GP, Magnuson JJ, McDowell WH, Melack JM, et al. 2011. An integrated conceptual framework for long-term social–ecological research. *Frontiers in Ecology and the Environment* 9:351–357.
COST [European Cooperation in Science and Technology]. 2012. Enhancing the resilience capacity of sensitive mountain forest ecosystems under environmental change (SENSFOR). ESSEM COST Action ES1203. http://www.cost.eu/domains_actions/essem/Actions/ES1203; accessed on 10 October 2013.
Fernández-Giménez ME, Fillat F. 2012. Pyrenean pastoralists' ecological knowledge: Documentation and application to natural resource management and adaptation. *Human Ecology* 40:287–300.
García-Cervigón AI, Olano JM, Eugenio M, Camarero JJ. 2012. Arboreal and prostrate conifers coexisting in Mediterranean high mountains differ in their climatic responses. *Dendrochronologia* 30:279–286.
García-Romero A, Munoz J, Andres N, Palacios D. 2010. Relationship between climate change and vegetation distribution in the Mediterranean mountains: Manzanares Head Valley, Sierra de Guadarrama (Central Spain). *Climatic Change* 100(3–4):645–666.
Garcia-Ruiz JM, Lana-Renault N. 2011. Hydrological and erosive consequences of farmland abandonment in Europe, with special reference to the Mediterranean region: A review. *Agriculture Ecosystems & Environment* 140:317–338.
Global Mountain Biodiversity Assessment. 2013. Establishing a mountain LTER network. http://gmba.unibas.ch/mountainLTER/mountainLTER.htm; accessed on 10 October 2013.
Hódar JA, Zamora R, Cayuela L. 2012. Cambio climático y plagas: algo más que el clima [in Spanish]. *Ecosistemas* 21(3):73–78.
Illa E, Carrillo E, Ninot JM. 2006. Patterns of plant traits in Pyrenean alpine vegetation. *Flora* 201:528–546.
IPCC [Intergovernmental Panel on Climate Change]. 2012. *Summary for Policy-makers: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.* Cambridge, United Kingdom: Cambridge University Press.
Körner C. 2003. *Alpine Plant Life: Functional Plant Ecology of High Mountain Ecosystems.* Heidelberg, Germany: Springer.
Körner C. 2009. Global statistics of "mountain" and "alpine" research. *Mountain Research and Development* 29:97–102.
Lasanta T, Marín-Yaseli ML. 2007. Effects of European common agricultural policy and regional policy on the socioeconomic development of the central Pyrenees, Spain. *Mountain Research and Development* 27(2):130–137.
Lindenmayer DB, Likens GE. 2009. Adaptive monitoring: A new paradigm for long-term research and monitoring. *Trends in Ecology and Evolution* 24:482–486.
López-Moreno JI, Vicente-Serrano SM, Moran-Tejeda E, Zabalza J, Lorenzo-Lacruz J, García-Ruíz JM. 2010. Impact of climate evolution and land use

changes on water yield in the Ebro basin. *Hydrology and Earth System Sciences* 7:2651–2681.
LTER-Spain Network. 2012. Bienvenidos a LTER-España [in Spanish]. http://www.lter-spain.net/; accessed on 10 October 2013.
Lurgi M, López BC, Montoya JM. 2012. Climate change impacts on body size and food web structure on mountain ecosystems. *Philosophical Transactions of the Royal Society of London Series B* 367:3050–3057.
MacDonald D, Crabtree J, Wiesinger G, Dax T, Stamou N, Fleury P, Gutierrez Lazpita J, Gibon A. 2000. Agricultural abandonment in mountain areas of Europe: Environmental consequences and policy response. *Journal of Environmental Management* 59:47–69.
McDougall KL, Khuroo AA, Loope LL, Parks CG, Pauchard A, Reshi ZA, Rushworth I, Kueffer C. 2011. Plant invasions in mountains: Global lessons for better management. *Mountain Research and Development* 31:380–387.
Moscoso DJ. 2006. Obstacles and opportunities for mountain development in Andalusia (Spain). *Mountain Research and Development* 26(1):81–83.
Nagy L. 2006. European high mountain (alpine) vegetation and its suitability for indicating climate change impacts. *Biology and Environment* 106B:335–341.
Ninot JM, Batllori E, Carrillo E, Carreras J, Ferré A, Gutiérrez E. 2008. Timberline structure and limited tree recruitment in the Catalan Pyrenees. *Plant Ecology & Diversity* 1(1):47–57.
Observatorio Cambio Global Sierra Nevada. 2013. Canal de noticias [in Spanish]. http://obsnev.es/; accessed on 10 October 2013.
Olano JM, Almería I, Eugenio M, von Arx G. 2013. Under pressure: How a Mediterranean high-mountain forb coordinates growth and hydraulic xylem anatomy in response to temperature and water constraints. *Functional Ecology.* http://dx.doi.org/10.1111/1365-2435.12144.
Pauli H, Gottfried M, Dullinger S, Abdaladze O, Akhalkatsi M, Benito Alonso JL, Coldea G, Dick J, Erschbamer B, Fernández Calzado R, Ghosn D, Holten JI, Kanka R, Kazakis G, Kollár J, et al. 2012. Recent plant diversity changes on Europe's mountain summits. *Science* 336:353–355.
Sanz-Elorza M, Dana ED, González A, Sobrino E. 2003. Changes in the high-mountain vegetation of the central Iberian Peninsula as a probable sign of global warming. *Annals of Botany* 92:273–280.
Scherrer D, Körner C. 2011. Topographically controlled thermal-habitat differentiation buffers alpine plant diversity against climate warming. *Journal of Biogeography* 38:406–416.
Sebastià M-T, De Bello F, Puig L, Taull M. 2008. Grazing as a factor structuring grasslands in the Pyrenees. *Applied Vegetation Science* 11:215–222.
Thomson Reuters. 2013. Thomson Reuters Web of Knowledge. http://www.isiknowledge.com; accessed on 12 May 2013.
von Arx G, Archer SR, Hughes MK. 2012. Long-term functional plasticity in plant hydraulic architecture in response to supplemental moisture. *Annals of Botany* 109:1091–1100.
Wilson RJ, Gutierrez D, Gutierrez J, Monserrat VJ. 2007. An elevational shift in butterfly species richness and composition accompanying recent climate change. *Global Change Biology* 13(9):1873–1887.
WWF [World Wildlife Fund]/Adena. 2013. *Bosques vulnerables a grandes incendios* [in Spanish]. Madrid, Spain: WWF/Adena.
Zamora R. 2010. Las áreas protegidas como observatorios del cambio global [in Spanish]. *Ecosistemas* 19(2):1–4.