European Research Council

ERC Starting Grant
Research proposal (Part B1)[1]

Biotic community attributes and ecosystem functioning: implications for predicting and mitigating global change impacts

BIOCOM

Principal Investigator: Fernando T. Maestre
Hosting Institution: Universidad Rey Juan Carlos, Móstoles, Spain
Project duration in months: 60

Proposal summary (half page, possibly copy/paste of abstract from administrative part A1)

Increases in nutrient availability and temperature, and changes in precipitation patterns and biodiversity are important components of global environmental change. Thus, it is imperative to understand their impacts on the functioning of natural ecosystems to predict its consequences, and to establish effective mitigation and adaptation actions. Substantial research efforts are being currently devoted to predict how biodiversity will respond to global change. However, little is known on the relative importance of biodiversity against other attributes of biotic communities, such as species cover and spatial pattern, as a driver of ecosystem processes. Furthermore, the effects of global change on the relationships between these attributes and ecosystem functioning are virtually unknown. The overall objective of this project is to evaluate the relationships between community attributes (species richness, composition, evenness, cover, and spatial pattern) and key processes related to ecosystem functioning (nutrient cycling, soil CO_2 flux and net CO_2 exchange, nitrogen fixation, litter decomposition, microbial functional diversity, and water infiltration and availability) in drylands under different global change scenarios. Its specific objectives are to: i) evaluate the relative importance of community attributes as drivers of ecosystem functioning using multiple communities (vascular plants, microorganisms and biological soil crusts) and a combination of manipulative field, natural and common garden experiments, ii) assess how multiple global change drivers (temperature, nutrient availability and precipitation) will affect key ecosystem processes, iii) test whether global change drivers modify observed community attributes-ecosystem functioning relationships, and whether these attributes modulate or ameliorate responses to global change, iv) develop models to forecast global change effects on ecosystem functioning in drylands, and v) set up protocols for the establishment of restoration and mitigation actions based on the results obtained. My proposed use of different experimental approaches, multiple biotic communities and spatial scales to test the same core ideas, as well as its integration with diverse modeling schemes, is novel, and will add further value to the project by allowing wider generalizations of the results obtained. Such integrated framework has not been tackled before when studying the impacts of global change on terrestrial ecosystems, and constitutes a ground breaking advance over current research efforts on this key environmental issue, which is a priority research for the European Union. The data gathered during the project will also provide an important database to test the generality of established paradigms, new modeling approaches to predict the consequences of global change on ecosystem functioning, and new methodologies to mitigate predicted impacts of global change in terrestrial ecosystems.

[1] Instructions for completing Part B1 can be found in the Guide for Applicants on ERC Grant Schemes

Section 1a: *The Principal Investigator*

i. Scientific Leadership Profile (max 2 pages)

During my Ph.D. at the University of Alicante, I was trained as a community ecologist with a strong emphasis on quantitative statistical methods and on field-based, applied research (restoration of degraded ecosystems in semiarid areas using environmental heterogeneity and plant-plant interactions). Some of my early (Ph.D.) work on the topic of plant-plant interactions includes the following papers:

1) **Maestre, F. T.**, S. Bautista, J. Cortina & J. Bellot. 2001. Potential of using facilitation by grasses to establish shrubs on a semiarid degraded steppe. *Ecological Applications* 11: 1641-1655. Number of citations: 70
2) **Maestre, F. T.**, S. Bautista & J. Cortina. 2003. Positive, negative and net effects in grass-shrub interactions in Mediterranean semiarid grasslands. *Ecology* 84: 3186-3197. Number of citations: 63
3) **Maestre, F. T.** & J. Cortina. 2004. Do positive interactions increase with abiotic stress? A test from a semi-arid steppe. *Proceedings of the Royal Society of London B (Supplement)* 271: S331-S333. Number of citations: 44

This work provides the **first example** of the use of facilitation as an alternative, ecologically-sound, technique to restore degraded semi-arid environments (*Ecological Applications* article), and one of the first experimental demonstrations of specific mechanisms underlying positive and negative effects in a plant-plant interaction (*Ecology* paper). These studies have been highly influential among the scientific community, as indicated by the number of citations they have attracted. Other indicator of the relevance of this research is the fact that my Ph.D., which is freely available from the public repository of the University of Alicante (http://www.cervantesvirtual.com/FichaObra.html?Ref=8589), has been downloaded 3760 times since it was published in September 2002 (statistics consulted on 8th December 2008).

The skills acquired during my Ph.D. at the University of Alicante were complemented with the short-term research stays I have conducted at different internationally recognized research centers over the years (e.g. Rothamsted Research, UK, and Universities of Montana, Vermont and Duke, USA) and, specially, during my two-year post-doctoral stay at Duke University (USA) as a Fulbright fellow. During that stay I independently developed and leaded an original research program on global change using controlled environments, and had the chance to interact with (and learn from) some of the most prominent scientists in the fields of global change and desertification (James F. Reynolds, Robert B. Jackson, James S. Clark and William H. Schlesinger, among others). My post-doctoral work was **the first in evaluating** how the spatial heterogeneity in the distribution of soil nutrients –a common feature of most terrestrial ecosystems– interacts with several global change drivers (including the increase in atmospheric CO_2 concentration and changes in rainfall regimes and in species richness and composition) to determine the structure and functioning of plant communities. An indication of the novelty and relevance of this work is its publication in some of the most important scientific journals in the field of Ecology and Global Change (e.g. *Ecology*, *Global Change Biology*, *New Phytologist* and *Oecologia*, among others, see section iii for full references). One of the papers derived from this work also received the *Journal of Vegetation Science Editors´ Award 2006* as the third best paper published in the journal on that year (Maestre *et al.* 2006, *Journal of Vegetation Science* 17: 261-270). During my post-doc I also used the bibliographical resources available at Duke to conduct some quantitative syntheses on plant-plant interactions. Two important publications from this period are the following:

1) **Maestre, F. T.**, F. Valladares & J. F. Reynolds. 2005. Is the change of plant-plant interactions with abiotic stress predictable? A meta-analysis of field results in arid environments. *Journal of Ecology* 93: 748-757. Number of citations: 73

Article identified as "Highly cited" in the category "Environment/Ecology" by the Institute of Scientific Information (ISI). Web of Science/Essential Science Indicators, statistics consulted on 1st December 2008 Article identified as a "Core paper" in the field of plant-plant interactions by ISI. Web of Science/Essential Science Indicators, statistics consulted on 3rd December 2008

2) **Maestre, F. T.**, F. Valladares & J. F. Reynolds. 2006. The stress-gradient hypothesis does not fit all relationships between plant-plant interactions and abiotic stress: Further insights from arid environments. *Journal of Ecology* 94: 17-22. Number of citations: 31

Article identified as a "Core paper" in the field of plant-plant interactions by ISI. Web of Science/Essential Science Indicators, statistics consulted on 3rd December 2008

These articles have challenged the conceptual paradigm currently employed by researchers aiming to predict how biotic interactions change along abiotic stress gradients, and have set the ground for new conceptual and experimental developments of the topic. A good indicator of their impact is the large number of cites they have attracted and their identification as “core paper” and “highly cited” articles by ISI.

Since my return to Spain in October 2005, with a “Ramón y Cajal” Research Fellow, I have implemented an independent research program to evaluate the relative importance of the attributes of biotic communities on ecosystem functioning and to assess how this relationship changes along environmental gradients. This work is currently being published, and different articles are now under review in top-tier scientific journals (see section iii for details). Apart from setting up my own research program at the Rey Juan Carlos University, I have been involved in a series of international collaborations in different topics relevant for this proposal. Two important publications derived from this collaborative effort are the following:

1) Reynolds, J.F., D.M. Stafford Smith, E.F. Lambin, B.L. Turner II, M. Mortimore, S.P.J. Batterbury, T.E. Downing, H. Dowlatabadi, R.J. Fernández, J.E. Herrick, E. Huber-Sannvald, R. Leemans, T. Lynam, **F. T. Maestre**, M. Ayarza & B. Walker. 2007. Global desertification: Building a science for dryland development. *Science* 316: 847-851. Number of citations: 23

Article identified as “Highly cited” in the category “Environment/Ecology” by the Institute of Scientific Information (ISI). Web of Science/Essential Science Indicators, statistics consulted on 3rd December 2008

2) Brooker, R.W., **F. T. Maestre**, R. M. Callaway, C.L. Lortie, L. Cavieres, G. Kunstler, P. Liancourt, K. Tielbörger, J.M.J. Travis, F. Anthelme, C. Armas, L. Coll, E. Corcket, S. Delzon, E. Forey, Z. Kikvidze, J. Olofsson, F.I. Pugnaire, P. Saccone, K. Schiffer, M. Seifan, B. Touzard & R. Michalet. 2008. Facilitation in plant communities: the past, the present and the future. *Journal of Ecology* 96: 18-34. Number of citations: 12

Article identified as “Highly cited” in the category “Environment/Ecology” by the Institute of Scientific Information (ISI). Web of Science/Essential Science Indicators, statistics consulted on 3rd December 2008

The first introduces a new synthetic and multidisciplinary paradigm to evaluate desertification issues in any part of the world, and the second presents an updated “state of the art” of facilitation research. Both articles have been identified as “highly cited” articles by ISI, and are becoming reference papers in the study of desertification and plant-plant interactions, respectively.

My research has led to numerous publications in high quality international journals. Many of them are multi-author works, reflecting the collaborative approach that I take to research and the large number of connections established with other scientists (I am currently collaborating with researchers from Spain, USA, UK, Denmark, China, France, Canada, Portugal, The Netherlands, Australia, Chile, Argentina, Venezuela, Mexico, Brazil and Ecuador). However, it must be noted that I am the leading author of 69% of all my publications. My research activities and collaborative approach to research have given me an increasingly high profile within the ecological community. As a consequence, I was appointed in September 2006 to the Editorial Board of the *Journal of Ecology*, one of the most important ecological journals, being the youngest member of the Board since then. I am also the youngest member of the Editorial Boards of *Arid Land Research and Management*, one of the leading international peer-reviewed journals on fundamental and applied research of arid and semiarid soils, and of *Ecosistemas*, the official journal of the Spanish Association for Terrestrial Ecology and one of the primarily outlets for the divulgation of ecological research among the general public in Spanish-speaking countries.

Other measures of recognition of the value and interest of my research are the funds I have received from Spanish and international funding agencies and the circulation of my research among the Spanish and international media. Since October 2005 I have led five research projects totaling more than 460000 € (three of them are active right now), and in one of them (*INTERCAMBIO*, Table I) I am leading the work of 21 scientists from Spain and Chile. The results from my research have also been highlighted in newspapers and radio stations from Spain, Mexico, Chile, Peru, Argentina and the US (see http://www.escet.urjc.es/biodiversos/espa/personal/fernando/fernando_prensai.htm for details).

From the beginning of my research career I have not narrowed my scientific activities to a particular research topic or organism, and I have opened new and important research lines in the field of community ecology that have gone beyond the state of the art. The skills acquired over my research career have provided me with the ability to conduct innovative and multidisciplinary research on different aspects of the ecology of terrestrial ecosystems, and to manage appropriately the research funds I lead. Overall, my career so far demonstrates my value as an independent research leader, and my potential to become a reference in the field of terrestrial ecology.

ii Curriculum Vitae (max 2 pages)

Education

Ph.D. in Biology, awarded by the University of Alicante on 23th July 2002. Qualification: Extraordinary Award (Highest mark in Spain).
Bs.C. in Biology, awarded by the University of Alicante on 25th January 1999. Qualification: Extraordinary Award (Highest mark in Spain, best rank of the 1994-1998 Biology promotion).

Professional experience

"Ramón y Cajal" Research Fellow, Department of Biology and Geology, Rey Juan Carlos University (Spain), 01/10/2005-onwards
Postdoctoral Fulbright Fellow, Spanish Ministry of Education and Science, Department of Biology, Duke University (USA), 01/10/2003- 30/09/2005
Associate in Research, Department of Ecology, University of Alicante (Spain), 01/01/2003-30/09/2003
Graduate Research Fellow, Spanish Ministry of Education and Science Ministry, University of Alicante (Spain), 01/01/1999-31/12/2002
Undergraduate Research Fellow, Spanish Ministry of Education and Science, University of Alicante (Spain), 01/12/1997-30/05/1998

Publication record

I have published 57 articles in international, peer-reviewed, scientific journals included in the JCR database (five more are currently under review), 15 articles in peer-reviewed Spanish and international scientific journals not included in this database, 13 articles in popular Spanish journals, 15 book chapters and three whole books (in Spanish). I am also the main editor of a multi-authored book (in Spanish). These publications have received 705 citations so far, and my current *h index* is 15. I would like to highlight that the number of cites received by my publications have increased by over 80% during the last year (from 390 to 705 cites) and that my *h* index has increased by over 40% during the same period (from 11 to 15). In addition to the publications listed in the preceding and following sections, other publications relevant to this proposal are:

1) **Maestre, F. T.**, J. Cortina & S. Bautista. 2004. Mechanisms underlying the interaction between *Pinus halepensis* and the native late-successional shrub *Pistacia lentiscus* in a semiarid plantation. *Ecography* 27: 776-786.
2) **Maestre, F. T.**, J. Cortina, S. Bautista, J. Bellot & R. Vallejo. 2003. Small-scale environmental heterogeneity and spatio-temporal dynamics of seedling establishment in a semiarid degraded ecosystem. *Ecosystems* 6: 630-643.
3) Chu, C. J., **F. T. Maestre**, Xiao, S., J. Weiner, Y. S. Wang, Z. H. Duan & G. Wang. 2008. Balance between facilitation and resource competition determines biomass–density relationships in plant populations. *Ecology Letters* 11: 1189-1197.
4) Montès, N., **F. T. Maestre**, C. Ballini, V. Baldy, T. Gauquelin, M. Planquette, S. Greff, S. Dupouyet & J. B. Perret. 2008. On the relative importance of the effects of selection and complementarity as drivers of diversity-productivity relationships in Mediterranean shrublands. *Oikos* 117: 1345-1350.

Participation in research projects and funding ID

I have participated in 12 research projects leaded by other scientists (totaling more than 6,000,000 €). In addition to the projects listed in Table I, I have been also the principal investigator of the following projects obtained in competitive calls from public and private funding agencies:

Testing the effects of biodiversity and spatial pattern on ecosystem functioning: An experimental approach using biological soil crusts; Funded by the British Ecological Society (UK) with 34,018 € (May 2006-August 2008).
Ecosystem processes in Mediterranean steppes: relationships between composition, structure and function; Funded by the Comunidad de Madrid (Spain) with 30,500 € (December 2005- March 2007).

Currently I have funding from the British Ecological Society, from the BBVA Foundation and from the Spanish Ministry of Science and Innovation (MCINN) for conducting research related to this application (Table I). Two of these projects are directly derived from a previous version of this proposal, presented to the ERC 2007 Starting Grants (*BIOCHANGE*, proposal number 204316-2). It was recommended for funding, but finally did not get ERC support because lack of funds (it was ranked the 417 among the more than 9000 proposals presented). The British Ecological Society (BES) awarded me with a three-year studentship in January 2008 to fund a Ph.D. student in my lab, who is working in the development of Experiment 1.1 described below (section 1b). This experiment started in August 2008 thanks to a project awarded by the MCINN in a specific call to support researchers from Spanish host institutions who passed the ERC quality threshold but did not get ERC funding. I am also collaborating in the *EPES* project (Table I), which coordinates a research network between scientists from Spain and Latin America aiming to evaluate the composition/structure and functioning of a semiarid ecosystems along wide geographical gradients. However, *EPES* does not provide research funds, which need to be provided by each partner.

Table I. Current and foreseen proposals for work related to this ERC application.

Title	Funding scheme/ organization responsible	Participation	Size of the grant (in €)	Duration
Effects of global change on the structure and functioning of biological soil crust communities (231/1975)	Studentship / British Ecology Society	Principal investigator	88,150	01/04/2008 – 31/03/2011
Biotic community attributes and ecosystem functioning: implications for predicting and mitigating global change impacts	Complementary Actions / Spanish Ministry of Science and Innovation	Principal investigator	100,000	15/01/2009 – 14/01/2010
Plant-plant interactions and ecosystem functioning under global change (INTERCAMBIO)	Research program on conservation ecology/ BBVA Foundation	Principal investigator	200,000	02/07/2007 – 30/06/2010
Assessment of ecosystem processes in semiarid environments as a tool to mitigate global change impacts (EPES)	Research network/ Latin-American Program of Science and Technology for Development (CYTED)	Co-Investigator	102,000	01/05/2007 – 01/05/2010

My position within my University allows me to develop an independent research program, as I have no contractual obligations for teaching. However, the level of funding I have makes extremely difficult to recruit people. Therefore, I still need to participate in all the stages involved in research (including experimental setup and monitoring, and data curation and analysis), which constrains my productivity and my ability to become an independent research leader. A Starting Grant will provide me with the resources needed to establish my own research group within my Department, and to expand my research to cover key topics that cannot be afforded with my current level of funding. Such a grant will definitively consolidate my profile within the ecological and global change research community.

International Experience

Rothamsted Experimental Station (UK), Department of Statistics (15/06/1999 – 31/07/1999)
University of Montana (USA), Division of Biological Sciences (01/06/2000 – 31/08/2000)
Duke University (USA), Department of Biology (20/09/2001 – 20/12/2001)
Rothamsted Research (UK), Plant and Invertebrate Ecology Division (22/08/2003 – 12/09/2003)
Duke University (USA), Department of Biology (01/10/2003 – 30/09/2005)
University of Vermont (USA), Department of Biology (28/06/2007 – 31/08/2007)

Direction of Ph.D./Ms.C./undergraduate students and post-docs

I have been the director of two Ms.C. theses and of an undergraduate research project. I am currently mentoring four Ph.D. students, one Ms.C. student, one undergraduate student and two international post-docs in my department.

Editorial Responsibilities

Referee of more than 130 scientific papers for peer-reviewed international journals such as *Ecology Letters*, *Ecology*, *Ecological Applications*, *Proceedings of the Royal Society of London B*, *Journal of Ecology* and *Oikos*. Referee of 10 scientific projects for the National Research Agencies of Spain, France, Chile and the Czech Republic, the United States-Israel Binational Science Foundation (USA), the Andalusian Evaluation Agency (Spain) and the British Ecological Society (UK).

iii Early Achievement-Track-Record (max 2 pages)

Publications, as main author (without the presence as co-author of my PhD supervisors) in leading international peer-reviewed journals in my research field

1) **Maestre, F. T.**, F. Valladares & J. F. Reynolds. 2005. Is the change of plant-plant interactions with abiotic stress predictable? A meta-analysis of field results in arid environments. *Journal of Ecology* 93: 748-757. Number of citations (excluding self-citations): 66
2) **Maestre, F. T.**, F. Valladares & J. F. Reynolds. 2006. The stress-gradient hypothesis does not fit all relationships between plant-plant interactions and abiotic stress: Further insights from arid environments. *Journal of Ecology* 94: 17-22. Number of citations (excluding self-citations): 27
3) **Maestre, F. T.** 2004. On the importance of patch attributes, abiotic factors and past human impacts as determinants of plant species richness and diversity in Mediterranean semi-arid steppes. *Diversity and Distributions* 10: 21-29. Number of citations (excluding self-citations): 11
4) **Maestre, F. T.**, A. Escudero, I. Martínez, C. Guerrero & A. Rubio. 2005. Does spatial pattern matter to ecosystem functioning? Insights from biological soil crusts. *Functional Ecology* 19: 566-573. Number of citations (excluding self-citations): 8
5) **Maestre, F. T.**, M. Bradford & J. F. Reynolds. 2005. Soil nutrient heterogeneity interacts with elevated CO_2 and nutrient availability to determine species and assemblage responses in a model grassland community. *New Phytologist* 168: 637-650. Number of citations (excluding self-citations): 6
6) **Maestre, F. T.** & J. F. Reynolds. 2007. Amount or pattern? Grassland responses to the heterogeneity and availability of two key resources. *Ecology* 88: 501-511. Number of citations (excluding self-citations): 4
7) **Maestre, F. T.**, M. Bradford & J. F. Reynolds. 2006. Soil heterogeneity and community composition jointly influence grassland biomass. *Journal of Vegetation Science* 17: 261-270. Number of citations (excluding self-citations): 3
8) **Maestre, F. T.**, J. L. Quero, F. Valladares & J. F. Reynolds. 2007. Individual vs. population plastic responses to elevated CO_2, nutrient availability and heterogeneity: a microcosm experiment with co-occurring species. *Plant and Soil* 296: 53-64. Number of citations (excluding self-citations): 3
9) **Maestre, F. T.** & J. F. Reynolds. 2007. Biomass responses to elevated CO_2, soil heterogeneity and diversity: an experimental assessment with grassland assemblages. *Oecologia* 151: 512-520. Number of citations (excluding self-citations): 1
10) **Maestre, F. T.** & J. F. Reynolds. 2006. Spatial heterogeneity in nutrient supply modulates plant nutrient and biomass responses to multiple global change drivers in model grassland communities. *Global Change Biology* 12: 2431-2441. Number of citations (excluding self-citations): 1
11) **Maestre, F. T.**, Escolar, C., Martínez, I. & Escudero, A. 2008. Are soil lichen communities structured by biotic interactions? A null model analysis. *Journal of Vegetation Science* 19: 261-266. Number of citations (excluding self-citations): 1
12) **Maestre, F. T.**, R. M. Callaway, F. Valladares & C. Lortie. 2009. Refining the stress-gradient hypothesis for competition and facilitation in plant communities. *Journal of Ecology* (in press). Number of citations (excluding self-citations): Not published yet

In addition to these recently published articles, I would like to mention some articles related to this proposal that are currently under review, which provide a good example of the research program I have established at the Rey Juan Carlos University since 2005:

Maestre, F. T., M. D. Puche, M. A. Bowker, M. B. Hinojosa, I. Martínez, P. García-Palacios, A. P. Castillo, S. Soliveres, A. L. Luzuriaga, A. M. Sánchez, J. A. Carreira, A. Gallardo & A. Escudero. Shrub encroachment can reverse desertification in semiarid Mediterranean grasslands. *Proceedings of the National Academy of Sciences of the United States of America* (under review, submitted on 5th December 2008).
Maestre, F. T. & A. Escudero. Is the patch-size distribution of vegetation a suitable indicator of desertification processes? *Ecology* (under review, submitted on 13th November 2008).
Maestre, F. T., I. Martínez, C. Escolar & A. Escudero. On the relationship between abiotic stress and co-occurrence patterns: An assessment at the community level using soil lichen communities and multiple stress gradients. *Oikos* (under review, submitted on 30th August 2008).

Research monographs and chapters in collective volumes (as main author/editor).

1) **Maestre, F. T.** & Reynolds, J. F. 2009. Soil heterogeneity modulates responses to multiple global environmental changes in model grassland communities. In: J. F. Reynolds & T. H. Jones (eds.). *Seeking Ecological Mechanisms: Controlled Environments in Global Change Research*. Ecological Studies. Springer-Verlag, Berlin (in press).
2) **Maestre, F. T.**, A. Escudero & A. Bonet (eds.). 2008. *Introducción al Análisis Espacial de Datos en Ecología y Ciencias Ambientales: Métodos y aplicaciones*. Rey Juan Carlos University Press, Madrid, 850 pp. ISBN: 978-84-9849-308-5 (in Spanish).
3) **Maestre, F. T.**, J. F. Reynolds, E. Huber-Sannwald, J. Herrick & M. Stafford Smith. 2006. Understanding global desertification: Biophysical and socioeconomic dimensions of hydrology. In: P. D´Odorico & A. Porporato (eds.). *Dryland Ecohydrology*, pp. 315-332. Springer, Dordrecth. ISBN: 1-4020-4261-2.
4) **Maestre, F. T.** 2003. *Plantas Medicinales y Tóxicas del Término Municipal de Sax*. Comparsa de Moros and Sax City Council, Sax, 110 pp. ISBN: 84-607-7538-0 (in Spanish).
5) **Maestre, F. T.** 2002. *La restauración de la cubierta vegetal en zonas semiáridas en función del patrón espacial de factores bióticos y abióticos*. Fundación Biblioteca Virtual Miguel de Cervantes, Alicante, 386 pp. ISBN: 84-688-0089-9 (in Spanish).
6) **Maestre, F. T.** 2000. *El Medio Ambiente en Sax. Estado actual y propuestas de gestión*. University of Alicante and Sax City Council de Sax, Alicante, 192 pp. ISBN: 84-7908-591-6 (in Spanish).

Invited presentations to peer-reviewed, internationally established conferences and/or international advanced schools

1) The Second Annual Frontiers in Life Sciences Conference Series 2009 “Dynamic Deserts: Resource uncertainity in Arid Environments”. Tempe (AZ, USA), 26 February – 1 March 2009. Presentation of the invited oral communication “**Maestre, F. T.** Biotic interactions at multiple spatial scales: Their role in maintaining ecosystem structure along complex resource gradients”
2) European Science Federation/LESC Exploratory Workshop “Positive interactions, biodiversity and invasibility in a changing world”. Arcachon (France), 3 - 7 September 2006. Presentation of the invited oral communication “**Maestre, F. T.** Competition/facilitation mediated through changes in water availability in semi-arid environments”
3) Ecological Society of America 90^{th} Annual Meeting, Montreal (Canada), 7-12 August 2005. Presentation of the invited oral communication: “**Maestre, F. T.**, A. Escudero & J. F. Reynolds. Linking the spatial patterns of organisms to ecosystem function and management: Insights from semi-arid environments”.

International Prizes/Awards/Academy memberships

Bs.C. Extraordinary Award, awarded by the University of Alicante in January 1999.
Award for Academic Excellence, awarded by the Valencian Regional Government in May 1999.
“Ramón y Cajal” Research Fellowship, awarded by the Spanish Ministry of Education and Science in June 2004.
Ph.D. Extraordinary Award, awarded by the University of Alicante in January 2005.
Journal of Vegetation Science Editors´ Award 2006. Third Best Paper published in the journal on that year.

Memberships to Editorial Boards of International Journals.

Journal of Ecology, Associate Editor since September 2006, youngest member of the Editorial Board
Arid Land Research and Management, Associate Editor since November 2005, youngest member of the Editorial Board

Section 1b: *Extended Synopsis of the project proposal* (max 5 pages)

i. State-of-the-art and objectives

The recently released 4th Assessment Report of the Intergovernmental Panel on Climate Change (http://www.ipcc.ch/) provides unequivocal evidence of the increase of temperature worldwide. Such augments, together with increases in nutrient availability and atmospheric CO_2 concentration ([CO_2]), changes in precipitation patterns and in biodiversity, constitute key drivers of the global environmental change (hereafter referred as to global change) currently facing terrestrial ecosystems (Zavaleta *et al.* 2003). Inspired by an increasing concern on the ecological and economical consequences of its decline, biodiversity has been the subject of many studies conducted primarily with terrestrial plant communities, model microbial systems, and aquatic communities (Hooper *et al.* 2005). Albeit this research has led to major advances in describing the relationship between biodiversity and key functional processes, our ability to make strong generalizations on the functional role of biodiversity, and to extrapolate the results obtained so far to other types of communities is still quite limited. Furthermore, little is known on the relative importance of biodiversity against other co-occurring key community attributes as a driver of ecosystem functioning (Maestre *et al.* 2005).

Among the community attributes that may be relevant for ecosystem functioning, spatial pattern merits special attention. The presence of non-random patterns in the spatial distribution of organisms and ecological processes is the norm, rather than the exception, in most ecosystems (Fortin & Dale 2005). Theoretical and modeling studies highlight the importance of these patterns for ecosystem functioning, stability and dynamics (Tilman & Kareiva 1997). However, very few studies have empirically evaluated how changes in the spatial patterns of a community, *per se* (i.e. independently of other co-occurring community attributes), are directly related to ecosystem functioning (Maestre *et al.* 2005), and none of them has been conducted using experimental approaches. I hypothesize that, by influencing intra- and inter-specific interactions, individual performance and individual-environment interactions, the spatial pattern of ecological communities controls key ecosystem functional processes such as nutrient cycling and water infiltration and availability.

Substantial research efforts are being currently devoted to predict how biodiversity will respond to some components of global environmental change, such as climate change (Araújo & New 2007), invasions by exotic species (Fridley *et al.* 2007), land use (Zhou *et al.* 2006) or changes in [CO_2] and nutrient availability (Zavaleta *et al.* 2003). However, the impact of these global change drivers on the relationships between biotic community attributes (including biodiversity) and key functional processes is virtually unknown (Zhou *et al.* 2006). The very few studies evaluating joint changes in biodiversity and global change drivers on functional processes such as primary production have been conducted with herbaceous plants (Reich *et al.* 2004, Maestre & Reynolds 2006), and much remains unknown on the potential effects of global change on the ecosystem processes and services that are dependent on attributes of biotic communities. Expanding these studies to incorporate biotic attributes such as spatial pattern is essential to advance in our understanding of the effect of biotic community attributes on ecosystem functioning, to accurately predict the consequences of global environmental change on key processes for sustaining life on earth, and to establish effective mitigation actions.

The overall objective of this project is to evaluate the relationships between main attributes of biotic communities (spatial pattern, species richness, species composition, species evenness, and cover) and key ecosystem functional processes (nutrient cycling, soil CO_2 flux and net CO_2 exchange, nitrogen fixation, litter decomposition, microbial functional diversity, and water infiltration and availability) in dryland ecosystems under different global change scenarios. These ecosystems are a key terrestrial biome, covering 41% of Earth’s land surface and supporting over 38% of the total global population of 6.5 billion (Reynolds *et al.* 2007), and are highly vulnerable to global change and desertification (Körner 2000, Reynolds *et al.* 2007), two of the most important and pressing environmental and socio-economical issues currently faced by mankind. The specific objectives of this project are:

i) to evaluate the relative importance of community attributes as drivers of ecosystem functioning using multiple communities (vascular plants, microorganisms and biological soil crusts) and a combination of manipulative field, natural and common garden experiments.
ii) to assess how multiple global change drivers (temperature, nutrient availability and precipitation) will affect key ecosystem processes.
iii) to test whether global change drivers modify observed community attributes-ecosystem functioning relationships, and whether these attributes modulate or ameliorate responses to global change.

iv) to develop models to forecast global change effects on ecosystem functioning in drylands.
v) to set up protocols for the establishment of mitigation and/or adaptation actions based on the results obtained.

This project is highly relevant for the study of global change, as it aims to study the joint impacts of multiple community attributes and global change drivers on key ecosystem processes, and to examine the complexity of these interactions using an integrated framework. My proposed use of different experimental approaches, multiple biotic communities and spatial scales to test the same core ideas, as well as its integration with diverse modeling schemes, is novel, and will add further value to the project by allowing wider generalizations of the results obtained. Such integrated framework has not been tackled before when studying the impacts of global change on terrestrial ecosystems, and constitutes a ground breaking advance over current research efforts on this key environmental issue, which constitutes a priority research for the European Union. The data gathered during the project will also provide an important database to test the generality of established paradigms, new modeling approaches to predict the consequences of global change on ecosystem functioning, and new methodologies to mitigate predicted impacts of global change in dryland ecosystems. These will be important to stakeholders and land management agencies to aid in developing appropriate management strategies for lands that may already be impaired by historical overexploitation and mismanagement. In short, this project will have notable impact on existing theoretical and applied research regarding the effects of global change on community attributes and ecosystem functioning, and will "open the door" to new research lines concerning the functional role of community attributes and their importance as modulators of ecosystem responses to global change. I expect the research to be conducted to be published in top multidisciplinary journals such as *Science*, *Nature*, *Proceedings of the National Academy of Sciences USA* and *PLOS Biology*, as indicated by the journals evaluating my current research (see section 1a above for details).

ii. Methodology

The methodology of the project is based on the establishment of new field (both observational and experimental) and common garden experiments, the monitoring of experiments already running, the development of modeling tools, and the synthesis of all the data gathered during the project. This combination of approaches is appropriate to achieve the objectives of the project. Below I present a brief summary of the main research activities that will be carried out during its duration:

1) Field experiments. The following experiments will be set up and maintained in representative dryland ecosystems of Spain (steppes dominated by *Stipa tenacissima* rich in Biological Soil Crusts [BSC] communities, Mediterranean shrublands dominated by species such as *Quercus coccifera*, *Rhamnus lycioides* and *Rosmarinus officinalis*, and *Pinus halepensis* forests):

1.1) Impacts of multiple global change drivers on ecosystem functioning. This experiment will evaluate, using a factorial design, the effects of BSC (presence vs. absence), nutrient availability (control vs. nutrient addition as predicted by current nutrient deposition models), temperature (control vs. increased temperature as predicted by current climatic models), and rainfall (control vs. a reduction in rainfall as predicted by current climatic models) on key ecosystem functions (net CO_2 exchange, soil enzyme activities related to N, C and P cycles, soil water dynamics, litter decomposition, microbial functional diversity and N fixation). The attributes of BSC (cover, species richness, species diversity and spatial pattern) will be used in the design as covariates. The experiment will be replicated in two sites located in central and south-east Spain, respectively. It has been partially set up in one of the sites in August 2008, and will be fully set up during the first year of the proposal. This experiment will be monitored during the whole duration of the proposal.

1.2) Joint effects of BSC and plant attributes on ecosystem functioning along natural gradients. This observational study will evaluate how the biotic attributes of BSC and vascular vegetation (cover, species richness, species diversity and spatial pattern) influence ecosystem functioning (same variables as experiment 1.1) in three representative dryland ecosystems (*S. tenacissima* steppes, Mediterranean shrublands and *Pinus halepensis* forests) along a large geographical gradient (from the Center to SE Spain) including natural variations in rainfall, temperature and overall nutrient status. A minimum of 30 sites (dimensions 30 × 30 m) per ecosystem type, located in the same substrate type and orientation, will be selected for the study. The data from this study will be integrated within a large-scale database to be developed by the research network EPES (see Table I above). Within this network there are plans to establish experimental sites in drylands of Chile, Mexico, Venezuela, Brazil, Argentina and Ecuador (6-15 per country). In addition, and with the support of this Starting Grant, I will establish additional research sites (8-12 per country) in drylands of Australia, China, Morocco, Tunisia, Peru and the United States. These sites will be sampled using the same methodology, and the goal is to obtain a global database containing data from 200-250 sites located in representative dryland ecosystems of the world. This study will, for the first time, evaluate the relative importance of BSC, vascular vegetation and abiotic factors as drivers of ecosystem functioning and will complement the results of the experiment 1.1. It will be carried during the first three years of the proposal.

1.3) Biotic attributes and small-scale heterogeneity in ecosystem functioning. The principal investigator started in November 2006 an experiment where monthly measurements of soil respiration and seasonal measurements of nutrient cycling are being taken in 78 sampling points located in different microsites of a *S. tenacissima* steppe located in Central Spain (below *S. tenacissima* canopies, below *Retama sphaerocarpa* canopies, bare ground soil without BSC and bare ground soil with different BSC cover, richness and composition). This experiment aims to evaluate the relative importance of spatial pattern and other BSC attributes as drivers of ecosystem functioning. It will be continued during the five years of the project, so a long-term dataset can be obtained for the development of modeling activities (see below).

1.4) Restoration experiment. This experiment aims to test whether the results obtained from the previous experiments can be applied for the establishment of effective restoration and mitigation actions. It will be carried out using both BSC and vascular plants. At four sites located along an abiotic stress gradient determined by rainfall, I will establish experimental plots in eroded areas without BSC and low vascular plant cover. Different BSC and plant re-inoculation treatments will be established in order to maximize the recovery of ecosystem functioning (these will be set up according to the results of Experiments 1.1, 1.2, 1.3, 2.1 and 2.2). The experiment will be carried out during the last two years of the project.

2) Common garden experiments. Three large common garden experiments will be set up:

2.1) Spatial pattern-ecosystem functioning experiment 1. This microcosm experiment aims to test for the independent effects of species richness (2, 4, 8 and 16 species), evenness (maximal evenness vs. communities with a geometric distribution of abundances among species), and spatial pattern (clumped vs. random) on ecosystem functioning (soil CO_2 efflux, soil enzyme activities related to N, C and P cycles, and microbial functional diversity) using BSC-forming lichens. This experiment will be set up during the first year of the project, and will be monitored during the following three years.

2.2) Spatial pattern-ecosystem functioning experiment 2. This microcosm experiment, which is linked to Experiments 1.1 and 2.1, will independently test for the effects of species richness (4, 8 and 16 species), spatial pattern (clumped vs. random), temperature (control vs. a 4º annual increase in temperature), and rainfall (control vs. a 20% reduction in rainfall) on ecosystem functioning using BSC as a model system. Its major objective is to evaluate the relative importance of species spatial pattern and richness as modulators, *per se* (i.e. independently of other community attributes), of ecosystem responses to two major global change drivers. The experiment will be set up during the second year of the project, and will be monitoring during the following three years.

2.3) Spatial pattern-ecosystem functioning experiment 3. This common garden experiment aims to test, using a factorial design, for the independent effects of species richness (4, 8 and 16 species), spatial pattern (clumped vs. random), temperature (control vs. a 4º annual increase in temperature), and rainfall (control vs. a reduction in rainfall of 68 mm·year^{-1}) on the functioning of perennial herbaceous assemblages. It differentiates from current global change and biodiversity experiments in that it incorporates the spatial pattern of the community in the design. The experiment will be set up during the second year of the project, and will run for three years.

3) Modeling activities.

The data gathered in the field and common garden experiments will be used to set up predictive models of ecosystem functioning based on attributes of biotic communities, including spatial pattern and surrogates of biodiversity. A range of modeling approaches, including predictive (Bowker *et al.* 2006) and ensemble forecasting modeling (Araújo & New 2007), and global change scenarios (Schröter *et al.* 2005) will be tested to predict how changes in the attributes of plants and BSC biotic attributes may impact the functioning of semiarid ecosystems under global change. The following modeling activities will be carried out:

3.1) Development of predictive models at different spatial scales: Using the data gathered from Experiments 1.3 and 2.1, I will develop and validate a predictive model (Model 1) to describe small-scale changes in two basic ecosystem processes (soil CO_2 efflux and N cycling) using abiotic factors (soil moisture, organic matter content, texture and temperature) and attributes of BSC (species richness, evenness, cover and spatial pattern) and microbial (species richness and biomass) communities as predictors. Statistical approaches such as generalized linear models, logistic regression, generalized additive models and classification tree analysis (Thuiller *et al.* 2003) will be used on its development. In addition, I will also implement a model at a larger spatial scale (Model 2), using the data gathered in Experiment 1.2 and similar statistical approaches, to predict changes in soil CO_2 efflux and N cycling using site characteristics (climate, organic matter content, latitude, longitude, texture and nutrient content) and the attributes of BSC (species richness, evenness, cover and spatial pattern), microbial (species composition, richness and biomass) and plant (species richness, evenness, cover and spatial pattern) communities as predictors.

3.2) Adaptation and validation of available ecosystem models: In addition to the development of predictive models based on the data gathered from the different experiments, I will adapt the Patch Arid Land Simulator-Functional Types (PALS-FT; Reynolds *et al.* 2004) and its Community version (PALS-CM; Zimov *et al.* 1996) for their use in the areas surveyed with the Experiment 1.2. PALS-FT is a mechanistically-based ecosystem model that simulates processes such as soil CO_2 efflux, soil water dynamics, above- and belowground plant productivity, net CO_2 exchange, and nutrient cycling over time scales ranging from days to decades. PALS-CM is a phenomenologically-based model that simulates ecosystem changes occurring over longer time scales (decades to centuries). These models, which have been successfully used in different deserts of North America to simulate the effects of global change on ecosystem structure and functioning (Zimov *et al.* 1996, Reynolds *et al.* 2004, Shen *et al.* 2008), will be adapted to account for the characteristics of the plant species dominating the ecosystems studied, and to incorporate BSC into its current framework. The revised PALS models will be validated using the data gathered in Experiment 1.2.

3.3) Forecasting of potential impacts of global change on ecosystem processes: Both the predictive models developed (Models 1 and 2) and the ecosystem models adapted (PALS-FT and PALS-CM) will be used to conduct modeling experiments to decipher how multiple interactions of elevated CO_2, N availability, and differing precipitation regimes will interact to affect different plant functional types and ecosystem functional processes (mainly C, N, and water cycles). They will help to assess the relative importance of different global change drivers and community attributes on ecosystem functioning, and to discriminate the responsible mechanisms for the observed patterns. The data provided by the Experiments 1.1 and 2.2 will be used to validate the forecasts from Model 1. Predictions from Model 2 will be compared with those of the validated PALS model.

The modeling activities will start during the third year of the project, once enough data from the field experiments become available. The testing and development of these models may involve additional data not gathered in the experiments planned, as well as the evaluation of ecosystem models currently unavailable.

4) Synthesis and meta-analyses. Together with the modeling activities, the data gathered from all field and common garden experiments will be combined with those of published studies to conduct different syntheses and quantitative meta-analyses. At least three large meta-analyses will be conducted by the end of the project: i) an assessment of the relative importance of species richness, composition, evenness, spatial pattern and cover as drivers of ecosystem functioning; ii) the evaluation of the effects of joint changes in temperature, rainfall and nutrient availability on the performance of organisms (BSC, vascular plants and microorganisms) and on ecosystem processes depending on them (carbon, nutrient and water fluxes), and iii) the relative effects of aboveground and belowground communities on ecosystem functioning in drylands. These syntheses will complement the scientific papers derived from the different experiments proposed, and will also facilitate the dissemination of the results obtained from the project. In addition, and to contribute to this diffusion among non-scientific audiences, a web page will be developed. The data and associated metadata will also be posted on public repositories, such as the Data Registry of the Ecological Society of America (http://data.esa.org/) and the online archive developed by the Knowledge Network for Biocomplexity (http://knb.ecoinformatics.org/index.jsp). These actions will facilitate the use of the data gathered during the project in meta-analyses and syntheses by other scientists, providing an adding value to the research conducted and increasing its impact among the scientific community.

iii. Resources

The team that will conduct the research planned will be formed by eight members: myself as the principal investigator, six members recruited during the duration of the project and one Ph.D. student already working with me. All the members to be recruited will devote 100% of their working time to the project, and will have contracts with full health care/unemployment/retirement benefits according to Spanish laws. The profiles of the members to be recruited are the following:

1) *A post-doctoral research associate with background on community and ecosystems ecology*. He/she will be contracted during the first 3 years of the project, and will work in experiments 1.1, 1.2 and 1.3.
2) *A post-doctoral research associate with background on ecological modeling and forecasting*. He/she will be contracted during the last 2.5 years of the project, and will be responsible for testing, developing and validating the different modeling approaches (3.1, 3.2 and 3.3) presented above.
3) *A graduate student, with a Bs.C. in Biology, Environmental Sciences, Forest Engineering or related fields*. He/she will be contracted during the last 4 years of the project, and will conduct his/her Ph.D. research based on Experiments 1.4, 2.1, 2.2 and 2.3 outlined above.
4) *Two field assistants*. They will be contracted during the five years of the project, and will help researchers with the set up, maintenance and data gathering of all field and common garden experiments, as well as with data management and curation.
5) *A laboratory technician*. He/she will be contracted during the five years of the project, and will help researchers with the analysis in the laboratory of all the samples gathered during the field and common garden experiments.

I will devote the 75% of my working time to the project. Apart from coordinating the work of all the members to be recruited, and supervising both the *Ph.D.* student and the post-docs, I will take the lead on the syntheses and meta-analyses to be conducted by the end of the project. There is a Ph.D. student (Cristina Escolar) already working with me on the Experiment 1.1. She has been funded by the British Ecological Society for the period 2008-2011 (see above for details), and will join the team until the end of her fellowship.

The host institution has the basic infrastructure needed to carry out the research project, including fully equipped laboratories for conducting a wide range of plant and soil analyses and recently built plant growth facilities. Some pieces of equipment (e.g. a TDR system for soil moisture measurements, a San^{++} analyzer for nutrient analyses, a LI-COR 8100 Automated soil CO_2 system, microplate readers, spectrophotometers, gas chromatographers and other equipment for conducting different soil, molecular and microbiological analyses), and all the laboratory facilities and instrumental available at the host institution will be used for this project as needed. However, to fully achieve its objectives it is necessary to acquire some pieces of equipment. These include a LI-COR 6100 portable photosynthesis system to measure net CO_2 exchange, additional LI-COR 8100 and TDR units (justified by the simultaneous and intensive use of this equipment in different experiments) and weather stations.

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