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GIS and Spatial Analysis Meet Conservation: a Promising Synergy to Address Biodiversity Issues

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Global Commitments to Biodiversity Conservation

Human population reached impressive numbers in 2011. We are now 7 billion people on Earth and we are expected to be more than 9 billion in 2050 (United Nations Department of Economic and Social Affairs, Population Division, http://www.un.org/esa/population/unpop.htm, accessed 10 November 2011). In this scenario of rapid human population growth, achieving successful targets for biodiversity conservation will be one of the greatest challenges of humanity in the 21st century. In face of increasing biodiversity loss, another challenge will be to assure the continuous provision of ecosystems resources and services, on which human well being depends (MEA 2005; Hooper *et al.* 2005; Gallai *et al.* 2009; Brink *et al.* 2009; Barton & Pretty 2010; Butchart *et al.* 2010).

The need to reduce biodiversity loss is widely recognized and a worldwide concern (Rands *et al.* 2010). Since the first meeting of the Convention on Biological Diversity (CDB) in 1992, in Rio de Janeiro, the number of parties to the CDB increased from 150 to 193 countries. Several global conservation commitments have been agreed upon, with varying progresses. The first commitment of the CDB was the first to address all aspects of biological diversity, including genetic resources, species and ecosystems, and also to formally recognize them as 'a common concern of humankind' and an integral part of sustainable development.

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In 2002, the Parties to the CBD committed to significantly reduce the current rates of biodiversity loss and to contribute to poverty alleviation by 2010 (SCBD 2005). This target was subsequently endorsed by the World Summit on Sustainable Development and incorporated into the UN Millennium Development Goals in 2005 (UN 2011). The 2010 biodiversity target was therefore a commitment from all governments, including those that are not parties to the CBD (SCBD 2010). Crossed the 2010 deadline, the last CBD assessment about the biodiversity status (Global Biodiversity Outlook 3, SCBD 2010) delivered an undesirable message: the 2010 biodiversity target was not met. Empirical testing of 31 cross-disciplinary indicators, developed by the CBD framework itself, demonstrated that none of the 21 sub-targets following the overall target of reducing the rate of biodiversity loss by 2010 was achieved at the global level, although some were partially or locally achieved (SCBD 2010; Butchart *et al.* 2010; Hoffmann *et al.* 2010). This assessment by the CDB delivered the clear message that the Earth's ecosystems are approaching tipping points beyond which they may be irreversibly degraded, with dire consequences for all life on Earth (Leadley *et al.* 2010). As a response to this message, a new global commitment to conservation of biodiversity was established in the historical Nagoya biodiversity summit (SCBD 2011) when a Strategic Plan for Biodiversity was adopted. This strategic plan is a ten-year framework (2011-2020) for action by all countries and stakeholders to safeguard biodiversity and the benefits it provides to people. As part of this strategic plan, 20 targets, known as the Aichi Biodiversity Targets, were proposed and supported by governments, who committed to establish national conservation targets. The Strategic Plan includes a 2050 vision and 2020 mission for biodiversity, as well as means for implementing and monitoring progress towards shared global objectives.

Distinct organizations, including the Group on Earth Observations Biodiversity Observation Network (GEO BON), NASA, DIVERSITAS, the United Nations Environment Program - World Conservation Monitoring Centre (UNEP-WCMC), the International Union for Conservation of Nature (IUCN), through frameworks and initiatives like GEO BON GEOPortal, GBIF, IUCN Red Data List, Barometer of Life (Scholes *et al.* 2008; Stuart *et al.* 2010; Hoffmann *et al.* 2011; GEO BON 2011) are now engaged in monitoring the progress of the Aichi Biodiversity Targets implementation.

Biodiversity Conservation and Geospatial Analysis

Monitoring of biodiversity at the global, national and local levels largely depends on the analysis of spatial data (Scholes *et al.* 2008; Horning *et al.* 2010; Skidmore *et al.* 2011; Cagnacci *et al*. 2010). It is a consensus among ecologists that the overwhelming majority of data on biodiversity exhibit strong spatial patterns, which are often driven by biological processes spatially structured (Rangel *et al.* 2006; Carl & Kuhn 2007). The increasingly recognition that ecological systems present complex, hierarchical and multiscale nature (Levin 1998; Wu & Li 2006; Olden *et al.* 2006) highlights the need to build more robust, multiscale and flexible models to assist the discussion of issues related to biodiversity conservation and management. In fact, international community and its institutions have increasingly invested in the collection of geospatial data required for ecological and environmental analysis to satisfy international obligations (Skidmore *et al.* 2011).

In this context, the combination of satellite remote sensing, Global Positioning System (GPS), and integrative tools such as GIS is an important complimentary system to biological ground-based studies (Murthy *et al.* 2003; Cagnacci *et al.* 2010). Together, these technologies form the basis for geoinformatics. Fortunately, new technologies are dramatically improving the collection and analysis of biodiversity information. For example, these increasingly sophisticated monitoring systems, consisting of satellite, air, land and ocean-based instruments, are being interlinked through the Group on Earth Observations (GEO) to form a Global Earth Observation System of Systems (GEOSS), that have arms representing nine Social Benefit Areas: disasters, health, energy, climate, agriculture, ecosystems, biodiversity, water, and weather. The biodiversity arm is the Group on Earth Observations Biodiversity Observation Network (GEO BON) which is to be a system of systems coordinating satellite observations of ecosystems and other components of biodiversity with *in situ* surveys and inventories of species and relevant genetic information (Scholes *et al.* 2008; Horning *et al.* 2010). Geoinformatics (Remote Sensing, GIS, GPS etc.) is one of the most promising frameworks to promote the integration of data and analysis from distinct scales (spatial and temporal) and organizational levels, in an approach that could deal with the hierarchical relationships inherent in biodiversity (Blaschke 2006).

The Geographic Information Systems (GIS) are integrative computer environments for capturing, storing, retrieval, processing, analysis and display of geographically referenced data, arranged to allow information gain addressed to the intended goal (Xavier-da-Silva *et al.* 2001; Smith *et al.* 2007). GIS instrumentation can be a valuable tool to the environmental and ecological analysis, providing improvements like: a) include the spatial dimension in the analysis of the target phenomena in a consistent and effective way; b) deal with the diverse nature of the growing, dynamic, diversified and multidisciplinary set of variables involved in biodiversity analysis; c) operationalize approaches respectful of the complex, multiscale, hierarchical structures of environmental systems, thereby providing a more holistic view of the environment; d) optimize the time and manner of obtaining analytical and/or synthetic information, turning the decision support more robust; e) increase the predictive modeling capacity, f) generate information both accurate and easy to understand, respecting the differences between the actors involved and improving the institutional and private cooperation. In addition, the combination of Geoinformatics and Ecoinformatics is a promising field that may play a role in the development and testing of models describing real environmental systems at multiple scales, and the adoption of these new advanced interdisciplinary approaches has great potential to optimize decision support for biodiversity conservation and management (Recknagel 2003; Green *et al.* 2005; Olden *et al.* 2006).

Conservation GIS and Spatial Analysis N&C Special Issue

Recognizing the promising role that geospatial data and analysis could play in the biodiversity conservation arena (Convis 2001), the Society for Conservation GIS (SCGIS) was created in the USA in 1997. The mission of the SCGIS is to build community, provide knowledge, and support individuals using GIS and science for the conservation of natural resources and cultural heritage. The SCGIS assists conservationists worldwide in using GIS through communication, networking, scholarships, and training. The Brazilian chapter of SCGIS (SCGIS-BR) was launched in the beginning of 2006. SCGIS-BR is an association formed by researchers from different institutions in Brazil that have in common the use of geospatial data and analysis for biodiversity conservation. During the "I Meeting of Society for Conservation GIS - Brazil" in 2009, the associated members pointed that the publication of materials to disseminate the use of geospatial analysis for conservation would be one of the primary goals of the SCGIS-BR between 2010-2012. We decided to organize two bibliographic products, a book and a special issue to be published in a scientific journal. The book focus would be GIS applications to biodiversity conservation in Brazil, portraying case studies that have resulted in concrete conservation actions (Paese *et al.* in press), whereas the special issue would be a collection of scientific articles emphasizing theoretical and methodological developments of GIS and spatial analysis for biodiversity conservation and management. We believe that *Natureza & Conservação (N&C)* is the adequate vehicle for this special issue. Published by Brazilian Association of Ecological Science and Conservation (ABECO), *Natureza & Conservação* is devoted to publish scientific papers that focus on new researches and conceptual developments on conservation science to reach different society institutions including researchers, conservationists, technicians and decision makers.

In the next sections of this editorial, we provide an overview of the global research publication on "Conservation GIS and Spatial Analysis", through a scientometric approach. This overview is introductory to this *N&C* Special Issue on "Conservation GIS and Spatial Analysis" and it describes the general trends and characteristics of the publication, as well as current emerging issues on this topic and examines the relationships between these global patterns and the contributions of the Special Issue.

Publication trends and patterns in Conservation GIS & Spatial Analysis

We used a scientometric approach to evaluate the academic production on "Conservation GIS & Spatial Analysis", underlining the relationships of this topic with the broader and neighbors research fields of "Conservation", "GIS" and "Spatial Analysis". Scientometric and bibliometric analysis cover different methods that aim to quantify and assess trends and characteristics in scientific production in a particular science area. These analyses can be useful tools for evaluating the results of scientific activity, providing a synoptic overview of the research area, as well as identifying peculiarities (*e.g.* hegemony of knowledge), gaps or biases (*e.g.* temporal, taxonomic, geographic) that require further attention of the scientific community (Verbeek *et al.* 2002; Tian *et al.* 2008; Siqueira *et al.* 2009).

To quantitatively characterize the scientific activity related to "Conservation GIS & Spatial Analysis", we performed scientometric analysis to data retrieved from the ISI Web of Science (WoS) scientific publication database, via Thompson Institute for Scientific Information's Web of Knowledge platform (http://isiwebofknowledge.com). To provide data to compare scientific production associated to "Conservation GIS & Spatial Analysis" with those related to the fields of "Conservation", "GIS" and "Spatial Analysis", we search WoS database for articles published between 1945 and 2010, using ["*conservation*"], ["*GIS*" or *"geographic* information system*"*], ["*spatial analysis*"], and ["*conservation*" and ("*GIS*" or *"geographic* information system*"*) or "*conservation*" and "*spatial analysis*"] as the keywords to search parts of titles, abstracts, or keywords. As the search terms "*conservation*" and "*spatial analysis*" extracted a huge number of articles, with many records from fields that have little relation to the target thematics (*e.g.* physics, planetary science, and neurology), we restricted the searches to the two major science categories, plus "Biodiversity Conservation".

Publication trends

We retrieved 4,828 articles related to "Conservation GIS & Spatial Analysis" and published between 1945 and 2010. In this time span, we found 33,781 published in Conservation", 13,210 in "Spatial Analysis", and 8,694 in "GIS". But only in 1989 we found the first article really associated to "Conservation GIS & Spatial Analysis" (*i.e.*, Miller *et al.* 1989). The first "GIS" article was published almost ten years before (Griffith 1980), while those related to "Spatial Analysis" (Hazen 1966) and "Conservation" (Moore 1962) were found more than forty years ago.

As the total history of the "Conservation GIS & Spatial Analysis" academic production is mainly restricted to the last 20 years, we analyzed the publication trends in the four target topics focusing in the articles published between 1990 and 2010. The articles published in this time span totalized 2,656 in "Conservation GIS & Spatial Analysis"; 7,862 in "GIS"; 13,847 in "Spatial Analysis"; and 29.264 in "Conservation". It can be observed in Figure 1 that during this period all the topics showed a growing trend in publication from 1990 on, when less than 0.5% of the global production output was recorded for all four, reaching more than 11% in 2010. A mean year increase rate of 1.2-fold was recorded for all except "Spatial Analysis" (1.4-fold).

A peak on global production output can be identified when the mean year increase on percentage of publication surpass 1.5-fold, and occurred once for "Conservation" (3-fold) and "Spatial Analysis" (6.5-fold), both in 1991 (Figure 1). In the same year, a publication peak also occurred for "GIS" (2-fold), followed by a second peak in 1992 (1.6-fold). The first peak occurred for "Conservation GIS & Spatial Analysis" only in 1995 (2.3-fold), with a second one recorded in 2003 (1.6-fold) (Figure 1). The total global production output reached the mark of 500 articles published firstly in "Conservation" (1992) and "Spatial Analysis" (1993), followed by "GIS" (1995) and then by "Conservation GIS & Spatial Analysis", only in 2002. All these results indicate that "Conservation GIS & Spatial Analysis" can be considered a recent research theme, presenting a growing trend in publication that shows more similarities with production trends in "GIS", considered in exponential growth by Tian *et al.* (2006), than with those of the other two topics analyzed.

Authors

There were a total of 12,244 name occurrences of authors contributing 2,656 articles in "Conservation GIS & Spatial

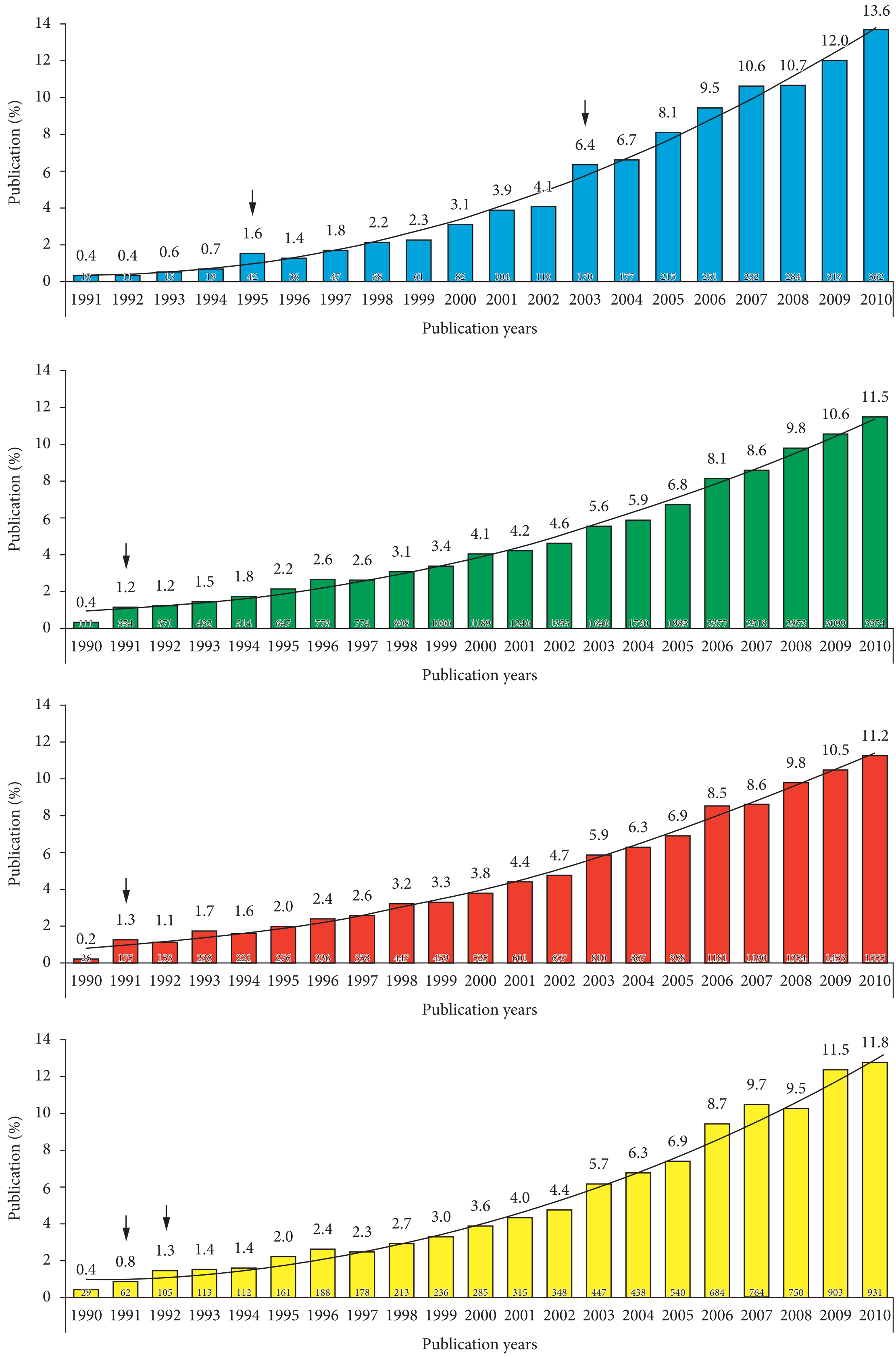

Figure 1. Production trend of scientific articles published on the topics "Conservation GIS & Spatial Analysis" (blue), "Conservation" (green), "Spatial Analysis" (red), and "GIS" (yellow), over the last 20 years (1990-2010). The number of articles is given inside the columns. Arrows indicate the publication peaks.

Analysis" from 1990 and 2010. Authors records for "GIS" totalized 30,755 (8,694 articles); 52,828 (13,847 articles) for "Spatial Analysis"; and 86,424 (29.264 articles) for "Conservation". The top 15 authors in each thematic are listed in Table 1 and showed in Figure 2. Four authors contributed with more than ten articles (Possingham HP, Lindenmayer DB, MacNally R, and Diniz-Filho JAF) and responded by more than 20% of the publications in "Conservation GIS & Spatial Analysis". Among the top 15 authors of this thematic five were also listed for "Conservation" (Possingham HP, Lindenmayer DB, MacNally R, Gaston KJ, Thomas CD), four were also listed for "Spatial Analysis" (Possingham HP, Lindenmayer DB, Diniz-Filho JAF, Gaston KJ), but no one for "GIS". "Spatial Analysis" and "GIS" had one author shared (Jerrett M). Brazilian authors figured among the top 15 only for "Conservation GIS & Spatial Analysis" (Diniz-Filho JAF) and "Spatial Analysis" (Diniz-Filho JAF, Bini LM). These results about who is contributing to the scientific production in "Conservation GIS & Spatial Analysis" indicate greater proximity with "Conservation", followed by "Spatial Analysis" and a lack of identity with "GIS" thematic.

Geographic distribution of publication

The articles published in "Conservation GIS & Spatial Analysis" between 1990 and 2010 were produced by authors from 104 different nationalities, while 148 were recorded for "GIS", 155 for "Spatial Analysis", and 190 for "Conservation". However, more than 35% of the articles production in all four topics was developed by authors from the United States of America, as can be observed in Table 2 and Figure 3. Five countries (USA, England, Australia, Canada and Spain) contributing to 90% of the publication in "Conservation GIS & Spatial Analysis". Among the top 15 countries contributing to publication in this field, 14 were also listed for "Conservation", with the same rank up to eighth position, while 13 countries were also shared by "Spatial Analysis" and 11 by "GIS". Six megadiverse countries are included in the top 15 contributors for "Conservation GIS & Spatial Analysis" and "Conservation" (USA, Australia, China, South Africa, Mexico, and Brazil). The contribution of Brazilian authors occupied the 15th position in "Conservation GIS & Spatial Analysis" and "Spatial Analysis", 12th in "Conservation", with no participation in "GIS". These results about the geographic distribution of the contributing authors to the scientific production in "Conservation GIS & Spatial Analysis" indicate that this thematic is more related to "Conservation" than to "Spatial Analysis" and "GIS".

Journals of publication

The articles produced from 1990 to 2010 and referring to "Conservation GIS & Spatial Analysis" were published in a diverse variety of 210 journals. The same was observed to articles related to "Spatial Analysis", "Conservation" and "GIS", that were published respectively in 350, 364 and 486 different journals. More than 35% of the articles in all four topics were published in the top 15 journals showed in Table 3 and Figure 4. "Conservation GIS & Spatial Analysis" and "Conservation" shared ten journals, with the same rank up to third position, while six journals are also shared by "Spatial Analysis", and four by "GIS". About 20% of the total global production in "Conservation GIS & Spatial Analysis" resided in these three core journals: *Biological Conservation* (8.4%), *Conservation Biology* (5.5%), and *Biodiversity and Conservation* (5.5%). The same three journals also published

Table 1. Top 15 authors contributing to articles production on the topics "Conservation GIS & Spatial Analysis", "Conservation", "Spatial Analysis", and "GIS", over the last 20 years (1990-2010). *Indicate authors related to more than one topic.

Conservation and GIS or SA			Conservation			Spatial Analysis			GIS		
Authors	n	%	Authors	n	%	Authors	n	%	Authors	n	%
Possingham HP*	19	0.7	Possingham HP*	182	0.6	Wiegand T	47	0.3	Lee S	56	0.7
Lindenmayer DB*	13	0.5	Gaston KJ*	126	0.4	Legendre P	46	0.3	Li X	23	0.3
MacNally R*	12	0.5	Lindenmayer DB*	108	0.4	Diniz-Filho JAF*	34	0.2	Engel BA	18	0.3
Diniz-Filho JAF*	11	0.4	MacDonald DW	63	0.2	Gaston KJ*	31	0.2	Li J	17	0.2
Gaston KJ*	10	0.4	MacNally R*	54	0.2	Russo D	30	0.2	Seker DZ	16	0.2
Carroll C	10	0.4	Thomas CD*	52	0.2	Fortin MJ	25	0.2	Wang J	16	0.2
Lobo JM	10	0.4	Samways MJ	51	0.2	Possingham HP*	25	0.2	Esaki T	14	0.2
Rushton SP	10	0.4	McCarthy MA	50	0.2	Asner GP	21	0.2	Jerrett M*	14	0.2
Baguette M	9	0.3	Tscharntke T	50	0.2	Rubin Y	21	0.2	Srinivasan R	14	0.2
Boitani L	9	0.3	Brook BW	49	0.2	Bini LM	20	0.1	Baskent EZ	13	0.2
Hortal J	9	0.3	Peres CA	49	0.2	Hawkins BA	20	0.1	Jensen JR	13	0.2
Richardson DM	9	0.3	Sutherland WJ	47	0.2	Lindenmayer DB*	20	0.1	Shi WZ	13	0.2
Rouget M	9	0.3	Cowling RM	45	0.2	Stenseth NC	20	0.1	Chang NB	12	0.2
Scott JM	9	0.3	Hermy M	45	0.2	Thuiller W	20	0.1	Cheng QM	12	0.2
Thomas CD*	9	0.3	Pressey RL	45	0.2	Jerrett M*	18	0.1	Hudak PF	12	0.2
Total	12244			86424			52828			30755	

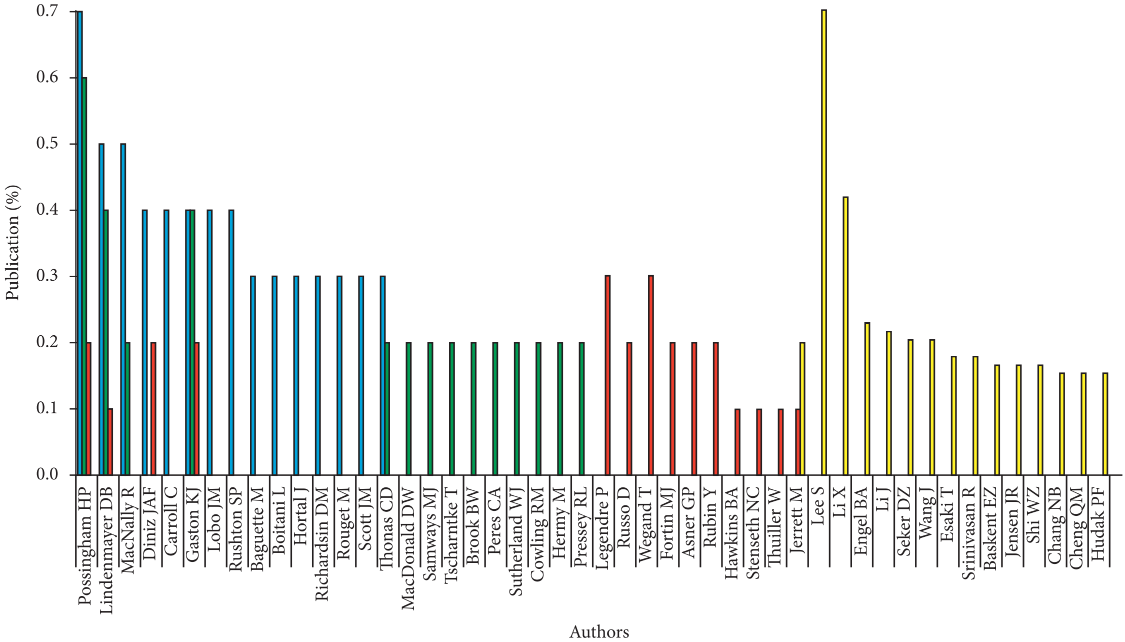

Figure 2. Top 15 authors contributing to articles production on the topics "Conservation GIS & Spatial Analysis" (blue), "Conservation" (green), "Spatial Analysis" (red), and "GIS" (yellow), over the last 20 years (1990-2010).

Table 2. Top 15 countries contributing to articles production on the topics "Conservation GIS & Spatial Analysis", "Conservation", "Spatial Analysis", and "GIS", over the last 20 years (1990-2010).

Conservation and GIS or SA			Conservation			Spatial analysis			GIS		
Countries/ Territories	n	%	Countries/ Territories	n	%	Countries/ Territories	n	%	Countries/ Territories	n	%
USA	1,061	39.9	USA	10,884	37.2	USA	5,646	40.8	USA	2,838	36.1
England	269	10.1	England	3,380	11.6	Canada	1,217	8.8	PR China	684	8.7
Australia	220	8.3	Australia	2,678	9.2	England	1,034	7.5	England	579	7.4
Canada	197	7.4	Canada	1,986	6.8	Germany	891	6.4	Canada	483	6.1
Spain	168	6.3	Spain	1,459	5.0	France	818	5.9	Germany	422	5.4
Germany	150	5.6	Germany	1,301	4.4	Australia	809	5.8	Italy	406	5.2
France	131	4.9	France	1,294	4.4	PR China	781	5.6	India	334	4.2
PR China	111	4.2	PR China	892	3.0	Spain	677	4.9	Australia	311	4.0
Italy	96	3.6	Netherlands	866	3.0	Italy	578	4.2	Spain	296	3.8
Netherlands	94	3.5	South Africa	857	2.9	Netherlands	454	3.3	Netherlands	264	3.4
South Africa	81	3.1	Scotland	812	2.8	Sweden	380	2.7	Turkey	254	3.2
Scotland	72	2.7	Brazil	811	2.8	Japan	341	2.5	France	226	2.9
Mexico	64	2.4	Sweden	801	2.7	Switzerland	332	2.4	Japan	171	2.2
Switzerland	64	2.4	Italy	753	2.6	Scotland	280	2.0	Switzerland	151	1.9
Brazil	62	2.3	Mexico	708	2.4	Brazil	242	1.7	Greece	136	1.7
Total	104			190			155			148	

more than 20% of the articles associated to "Conservation", highlighting the proximity of these two topics.

Subject categories

During the past 20 years, a total of 35 subject categories were identified by WoS in the articles referring to research topic of "Conservation GIS & Spatial Analysis", 49 in "Spatial Analysis", 51 in "GIS", and 54 in "Conservation". The top 15 subject categories are presented in Table 4 and Figure 5. Among the subject categories listed in "Conservation GIS & Spatial Analysis", 14 were shared by "Conservation", 11 by "Spatial Analysis", and 8 by "GIS". The most common subject category in all four research topics was *Environmental Science and Ecology*. In "Conservation GIS & Spatial Analysis" the second and third ranked subjects were represented by *Biodiversity Conservation* and *Physical Geography*. These positions were occupied by *Biodiversity*

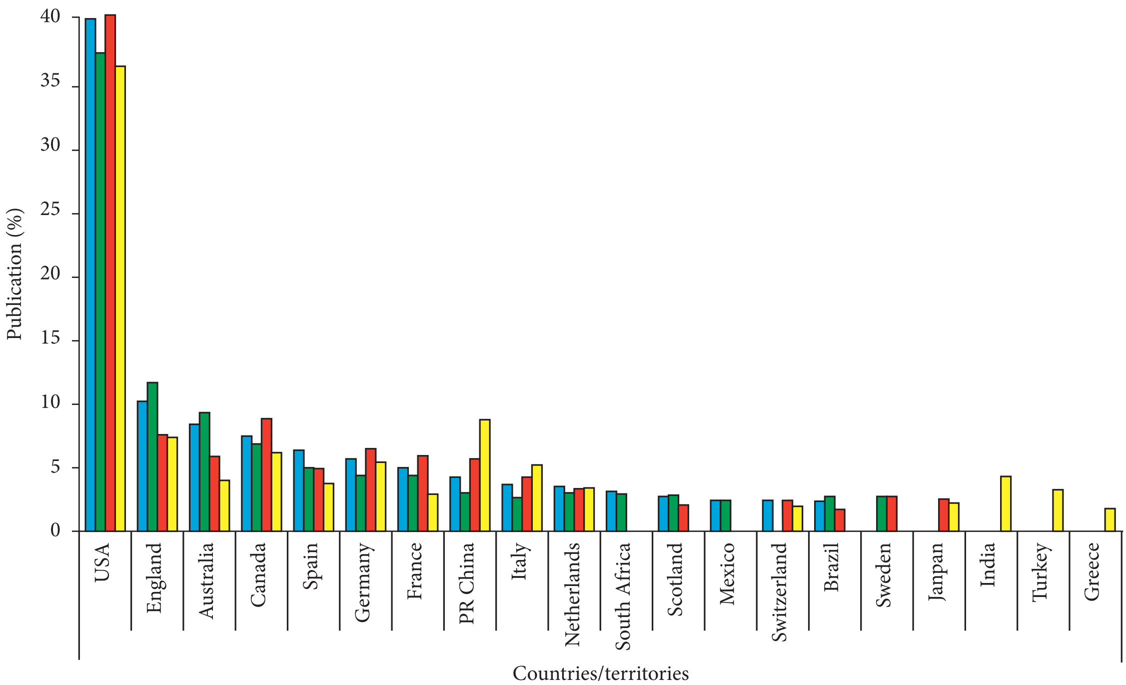

Figure 3. Top 15 countries contributing to articles production on the topics "Conservation GIS & Spatial Analysis" (blue), "Conservation" (green), "Spatial Analysis" (red), and "GIS" (yellow), over the last 20 years (1990-2010).

Conservation and *Evolutionary Biology* in "Conservation"; by *Marine Freshwater Biology* and *Water Resources* in "Spatial Analysis"; and by *Geology* and *Water Resources* in "GIS". Once again, regarding to the subject categories, there was more similarity among "Conservation GIS & Spatial Analysis" and "Conservation" topics.

Citation

For all topics analyzed, we identified the top 15 most cited papers in the last 20 years (1990-2010). The citation count was obtained from SCI (WoS) in November, 2011, representing the total number of times that a particular paper had been cited by all journals listed in the database. From the top 15 most cited papers identified in "Conservation GIS & Spatial Analysis", the first three ranked papers (Guisan & Zimmermann 2000; Hooper *et al.* 2005; Elith *et al.* 2006) were also listed in "Conservation", while another three were also shared by "Spatial Analysis" (Hooper *et al.* 2005; Elith *et al.* 2006; Phillips *et al.* 2006) and by "GIS" (Guisan & Zimmermann 2000; Faith 1992; Scott 1993). The most cited paper in "Conservation GIS & Spatial Analysis" and also in "GIS" (Guisan & Zimmermann 2000) and published in *Ecological Modelling* journal, was cited by 1586 times, an average of 132.1 times per year. The total citation for the first ranked paper in all four topics were very similar, but the average total citation per item computed by articles in "Conservation GIS & Spatial Analysis" reached 526.3, a value higher than those recorded for papers published in "GIS" (453.4) and lower than those in "Spatial Analysis" (955.5) and "Conservation" (1205.1). According to these results, citation patterns seem to be more similar between "Conservation GIS & Spatial Analysis" and "GIS" topics.

Current Focus and Research Issues in Conservation GIS & Spatial Analysis and the Special Issue

This section seeks to highlight what are the current focus and the research issues addressed by the "Conservation GIS & Spatial Analysis" academic community. To accomplish that task, we analyzed the 50 most cited articles published in this topic over the last three years (2008-2010) regarding to biodiversity organization level, geographical extent, research theme, and methods involved in the studies. Below we describe the patterns found in this set of recent articles, and establish the linkages with the contents of this Special Issue of *N&C*.

Biodiversity organization level

As can be observed in the Figure 6, among the top 50 most cited articles recently published in "Conservation GIS & Spatial Analysis", there were studies focusing on all biodiversity organization levels. Although landscape/ecosystem (56%) and community/species (44%) were most frequently represented, almost 20% of the articles addressed population/individual (8%) or population/genetic (10%) levels. In a similar way, virtually all the articles in this Special Issue focusing landscape/ecosystem or community/species levels, in equivalent proportions. Diniz-Filho & Bini (2011) address the genetic and molecular biodiversity level in an

Table 3. Top 15 journals publishing articles on the topics “Conservation GIS & Spatial Analysis”, “Conservation”, “Spatial Analysis”, and “GIS”, over the last 20 years (1990-2010).

Conservation and GIS or SA			Conservation			Spatial analysis			GIS		
Journals	**n**	**%**	**Journals**	**n**	**%**	**Journals**	**n**	**%**	**Journals**	**n**	**%**
Biological Conservation	223	8.4	Biological Conservation	2,813	9.6	Water Resources Res.	660	4.8	Photogr. Engin. Rem. Sensing	371	4.7
Conservation Biology	147	5.5	Conservation Biology	1,858	6.4	Remote Sensing of Environment	475	3.4	Comput. Geosciences	300	3.8
Biodiversity and Conservation	145	5.5	Biodiversity and Conserv.	1,732	5.9	Marine Ecology Progress Series	463	3.3	Env. Monit. Assess.	248	3.2
Ecol. Applications	117	4.4	Molecular Ecology	844	2.9	Molecular Ecology	369	2.7	Env. Geology	221	2.8
Landscape and Urban Planning	110	4.1	Conservation Genetics	780	2.7	Ecol. Modelling	363	2.6	Env. Management	216	2.7
Molecular Ecology	104	3.9	J. Applied Ecology	727	2.5	Ecology	345	2.5	Geomorphology	213	2.7
J. Biogeography	102	3.8	Ecol. Applications	651	2.2	Atmospheric Environment	316	2.3	J. Env. Management	197	2.5
Landscape Ecology	91	3.4	Env. Management	509	1.7	Landscape Ecology	304	2.2	Env. Modelling Software	184	2.3
J. Applied Ecology	89	3.4	Oryx	496	1.7	J. Biogeography	284	2.1	Landscape Ecology	162	2.1
Env. Management	76	2.9	J. Wildlife Management	495	1.7	Ecol. Applications	263	1.9	J. Coastal Research	152	1.9
Ecol. Modelling	62	2.3	J. Soil and Water Conserv.	455	1.6	Env. Monitoring and Assessment	262	1.9	J. Am. Water Resources Ass.	140	1.8
J. Wildlife Management	54	2.0	Aq. Conserv. Mar. Fresh. Ecosys.	446	1.5	Science of the Total Environment	205	1.5	J. Hydrology	138	1.8
Diversity and Distributions	50	1.9	Landscape and Urban Planning	436	1.5	J. Vegetation Science	198	1.4	Natural Hazards	133	1.7
Conservation Genetics	42	1.6	Agriculture Ecosystems Env.	421	1.4	Landscape and Urban Planning	193	1.4	Biological Conservation	130	1.7
J. Env. Management	42	1.6	Animal Conservation	414	1.4	Env. Science Technology	190	1.4	Sc. Total Env.	130	1.7
Total	210			364			350			486	

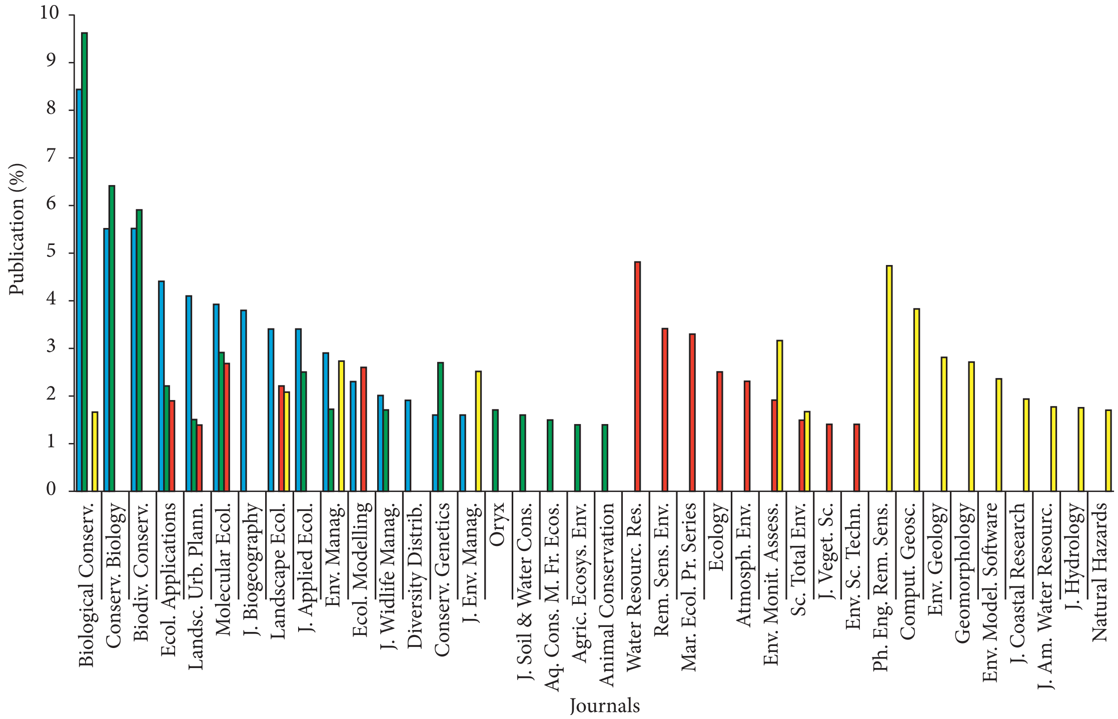

Figure 4. Top 15 journals publishing articles on the topics “Conservation GIS & Spatial Analysis” (blue), “Conservation” (green), “Spatial Analysis” (red), and “GIS” (yellow), over the last 20 years (1990-2010).

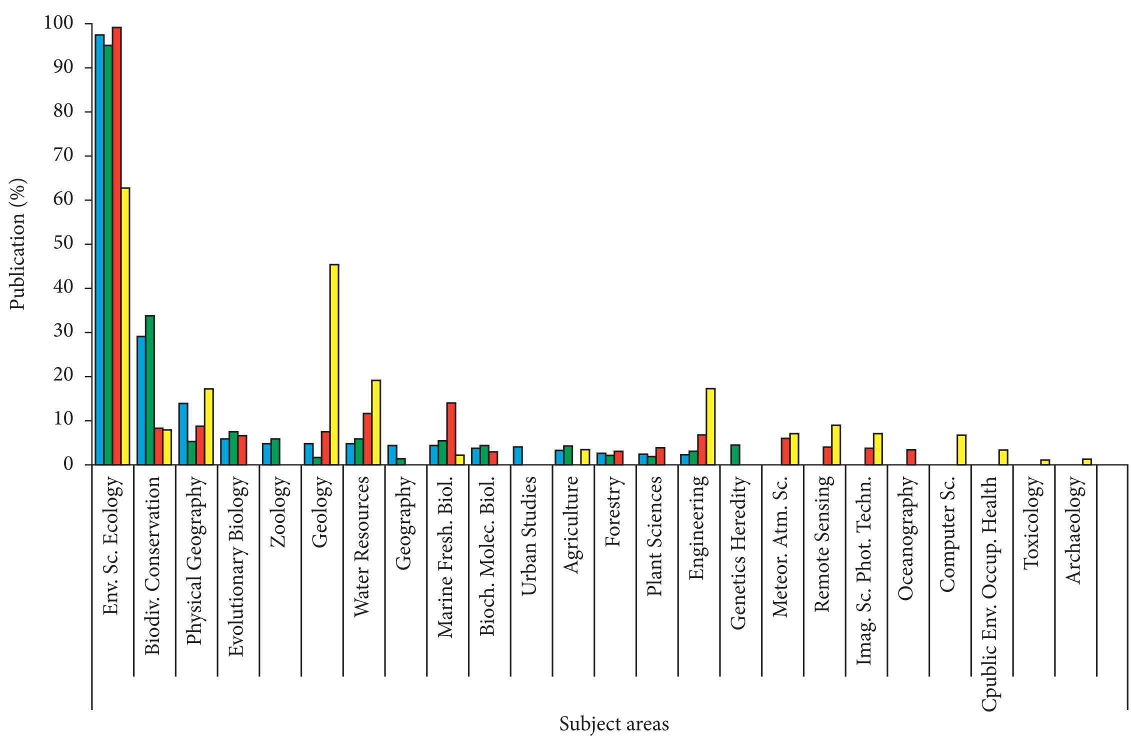

Figure 5. Top 15 subject categories related to the articles published in the topics “Conservation GIS & Spatial Analysis” (blue), “Conservation” (green), “Spatial Analysis” (red), and “GIS” (yellow), over the last 20 years (1990-2010).

Table 4. Top 15 subject categories related to the articles published in the topics "Conservation GIS & Spatial Analysis", "Conservation", "Spatial Analysis", and "GIS", over the last 20 years (1990-2010).

Conservation and GIS or SA			Conservation			Spatial analysis			GIS		
Subjet categories	**n**	**%**	**Subjet categories**	**n**	**%**	**Subjet categories**	**n**	**%**	**Subjet categories**	**n**	**%**
Environm. Sc. Ecology	2,615	97.5	Environm. Sc. Ecology	28,307	95.2	Environm. Sc. Ecology	13,851	99.4	Environm. Sc. Ecology	4,941	62.8
Biodiv. Conservation	779	29.0	Biodiv. Conservation	10,089	33.9	Marine Fresh. Biol.	1,928	13.8	Geology	3,579	45.5
Physical Geography	369	13.8	Evolutionary Biol.	2,215	7.5	Water Resources	1,623	11.6	Water Resources	1,516	19.3
Evolutionary Biology	158	5.9	Zoology	1,689	5.7	Physical Geography	1,211	8.7	Engineering	1,365	17.4
Zoology	131	4.9	Water Resources	1,670	5.6	Biodiversity Conservation	1,130	8.1	Physical Geography	1,340	17.0
Geology	126	4.7	Marine Fresh. Biol.	1,602	5.4	Geology	1,028	7.4	Remote Sensing	699	8.9
Water Resources	125	4.7	Physical Geogr.	1,539	5.2	Engineering	965	6.9	Biodiversity Conservation	614	7.8
Geography	113	4.2	Genetics Heredity	1,317	4.4	Evolutionary Biology	941	6.8	Meteorology Atmosph. Sc.	564	7.2
Marine Fresh. Biol.	113	4.2	Biochem. Molecular Biol.	1,288	4.3	Meteorology Atmosph. Sc.	851	6.1	Imaging Sc. Photogr. Techn.	556	7.1
Biochem. Molecular Biol.	111	4.1	Agriculture	1,238	4.2	Remote Sensing	567	4.1	Computer Sc.	546	6.9
Urban Studies	110	4.1	Engineering	918	3.1	Plant Sciences	549	3.9	Agriculture	275	3.5
Agriculture	89	3.3	Forestry	648	2.2	Imaging Sc. Photogr. Techn.	515	3.7	Public Env. Occup. Health	268	3.4
Forestry	67	2.5	Plant Sciences	598	2.0	Oceanography	477	3.4	Marine Freshwater biology	172	2.2
Plant Sciences	67	2.5	Geology	568	1.9	Forestry	429	3.1	Toxicology	96	1.2
Engineering	62	2.3	Geography	486	1.6	Biochemistry Molecular Biol.	424	3.0	Archaeology	77	1.0
Total	35			54			49			51	

integrated methodological and conceptual framework to biodiversity analysis.

Geographical extent

According to the geographical extent (Figure 7), the top 50 most cited articles encompassed all spatial scales, from local (12%) to global (14%). However, landscape (42%) and specially region coverage (78%) were predominant. Frequently, the studies focused on two spatial scales, from local to landscape and, more often, from landscape to region. The same pattern can be observed in this Special Issue, where studies covered all spatial scales, the regional extent was the most frequent, and some studies were developed across different scales (*e.g.* Jenkins *et al.* 2011; Crouzeilles *et al.* 2011; Holvorcem *et al.* 2011).

Research themes

From the analysis of the recent most cited articles published in "Conservation GIS & Spatial Analysis", top 10 research themes emerged as follow (Figure 8): 1) spatial patterns of biodiversity (*e.g.* abundance, richness, rarity, diversity, endemism etc.); 2) biodiversity assessment, management and monitoring; 3) threats and impacts on biodiversity (*e.g.* deforestation, fire, fisheries, logging, diseases, biological invasion etc.); 4) habitat fragmentation and connectivity; 5) measures of ecosystems properties, goods and services

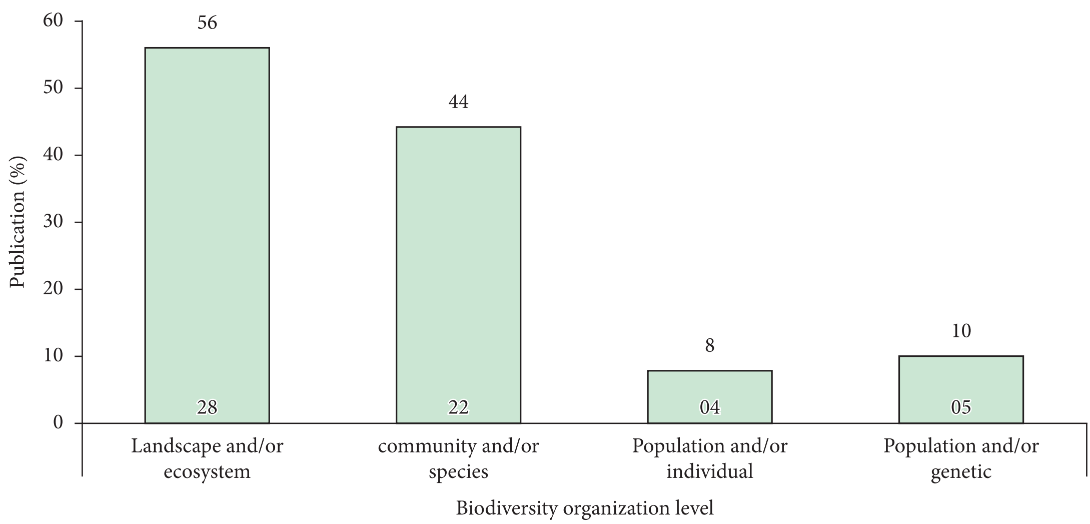

Figure 6. Biodiversity organization level addressed by the 50 most cited articles recently published in the topics "Conservation GIS & Spatial Analysis", over the last three years (2008-2010). The number of articles is given inside the columns.'

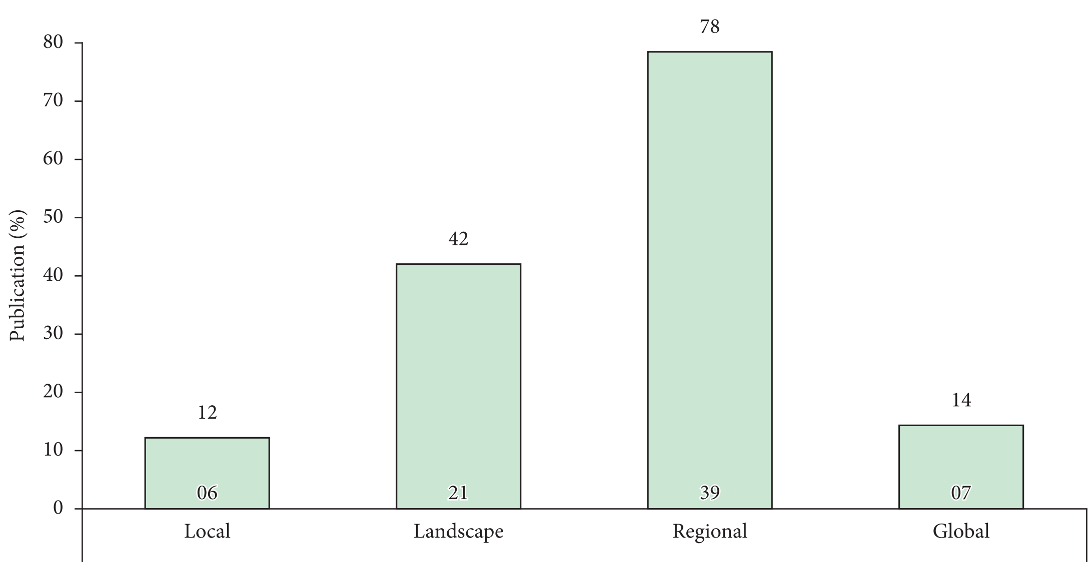

Figure 7. Geographical extent covered by the 50 most cited articles recently published in the topics "Conservation GIS & Spatial Analysis", over the last three years (2008-2010). The number of articles is given inside the columns.

(*e.g.* productivity, carbon storage, recreation and tourism, fresh water provision, water regulation, food provision etc.); 6) environmental change (*e.g.* land cover/land use change, climate change, sea level change, mass movements etc.); 7) space use and movements; 8) area conservation prioritization; 9) scale; and 10) spatial support decision.

These top 10 current themes show great concordance with the emerging issues in spatial ecology pointed by Skidmore *et al.* (2011), and are well represented in this special issue. "Spatial patterns of biodiversity", the most frequent research theme, was addressed by 80% of the articles (see Diniz-Filho & Bini 2011; Werneck *et al.* 2011; Hortal & Lobo 2011; Souza *et al.* 2011). "Threats and impacts on biodiversity" and "biodiversity assessment, management and monitoring" were the research theme in more than 30% of the papers (see Esteves *et al.* 2011; Koblitz *et al.* 2011). The themes "habitat fragmentation and connectivity" and "measures of ecosystems properties, goods and services" were addressed by more than 25% of the papers, and are also present in this special issue (respectively in Crouzeilles *et al.* 2011; Holvorcem *et al.* 2011; Ladle *et al.* 2011). Almost 20% of the papers were related to "environmental change", theme that was present in the special issue associated to climate change (Souza *et al.* 2011) and land use change (Dobrovolski *et al.* 2011). The issues "area conservation prioritization" or "spatial support decision" were present in 18% of the papers, being well represented in this special issue (Lourival *et al.* 2011; Jenkins *et al.* 2011; Crouzeilles *et al.* 2011; Holvorcem *et al.* 2011; Lemes *et al.* 2011). "Scale" was addressed by 10% of the papers and also by Diniz-Filho & Bini (2011). The topic "space use and movements" was present in 8% of the papers and although considered an emergent and promising area, with the advances of Global positioning system (GPS) telemetry technology (Cagnacci *et al.* 2010), was the only theme not represented in this special issue of *N&C*.

Methodological approaches

The analysis of the recent most cited articles published in "Conservation GIS & Spatial Analysis" indicated the following top 10 methods among the more frequently employed (Figure 9): 1) GIS basic and/or advanced functionalities; 2) landscape or connectivity analysis; 3) spatial statisctics or geostatistics; 4) remote sensing analysis; 5) species distribution modeling; 6) time series analysis or scenarios simulation; 7) phylogeographic or landscape genetics analysis; 8) spatial conservation prioritization tools; 9) multicriterial analysis, 10) GPS and telemetry.

As expected, all the papers used some GIS functionality, and therefore when we mentioned a method, we mean their combination with GIS. Many of these top 10 methods are also among the emergent methods used in spatial ecology, highlighted by Skidmore *et al.* (2011). "Landscape or connectivity analysis" was the most frequent method, employed by more than 30% of the studies and also by five articles in this special issue (Freitas *et al.* 2011; Crouzeilles *et al.* 2011; Holvorcem *et al.* 2011; Esteves *et al.* 2011; Koblitz *et al.* 2011). About 30% of the studies used methodological approaches including "spatial statisctics or geostatistics", "remote sensing analysis" or "species distribution modeling" (see respectively Hortal & Lobo 2011; Freitas *et al.* 2011; Souza *et al.* 2011). "Time series analysis or scenarios simulation" was employed by more than 15% of the studies (see Ladle *et al.* 2011; Dobrovolski *et al.* 2011; Souza *et al.* 2011). "Phylogeographic or landscape genetics analysis" were present in 10% of the papers (see Diniz-Filho & Bini 2011), whereas more than 5% of the studies used "multicriterial analysis" or "spatial conservation prioritization tools" (see Lourival *et al.* 2011; Lemes *et al.* 2011). "GPS and telemetry", considering an emergent approach by Cagnacci *et al.* (2010), was present in 2% of the articles, but was not represented in this special issue.

Concluding Remarks

We are now 7 billion people on Earth, and the numbers are growing. In such a scenario of the increased consumption of natural resources, the biodiversity conservation emerges as one of the greatest challenges facing humanity in the 21st century. However, biodiversity losses at different spatial scales are still increasing and are a worldwide concern (MEA 2005; Butchart *et al.* 2010; Rands *et al.* 2010). International commitments towards reducing biodiversity losses have been established, with clear strategic plans and targets (SCBD 2005, 2010). Monitoring and assessment of the progress towards global conservation targets are important components of global commitments and many institutions from academy, government and organized society are now engaged in these tasks (Scholes *et al.* 2008; Stuart *et al.* 2010; Hoffmann *et al.* 2011; GEO BON 2011). Monitoring and assessment of biodiversity at the global, national and local levels largely depend on the analysis of spatial data (Scholes *et al.* 2008; Horning *et al.* 2010; Skidmore *et al.* 2011; Cagnacci *et al.* 2010). The combination of remote sensing, GPS, and integrative tools such as GIS is an important complimentary system to biological ground-based studies, and new technologies are dramatically improving the collection and analysis of biodiversity information (Murthy *et al.* 2003; Scholes *et al.* 2008; Horning *et al.* 2010). Indeed, Geoinformatics seems to be one of the most promising frameworks to promote the integration of data and analysis from distinct scales (spatial and temporal) and organizational levels, in an approach that could deal with the complex, multiscale and hierarchical relationships inherent to biodiversity (Blaschke 2006). Additionally, the combination of Geoinformatics and Ecoinformatics is a promising field that has great potential to optimize decision support for biodiversity conservation and management (Recknagel 2003; Green *et al.* 2005; Olden *et al.* 2006).

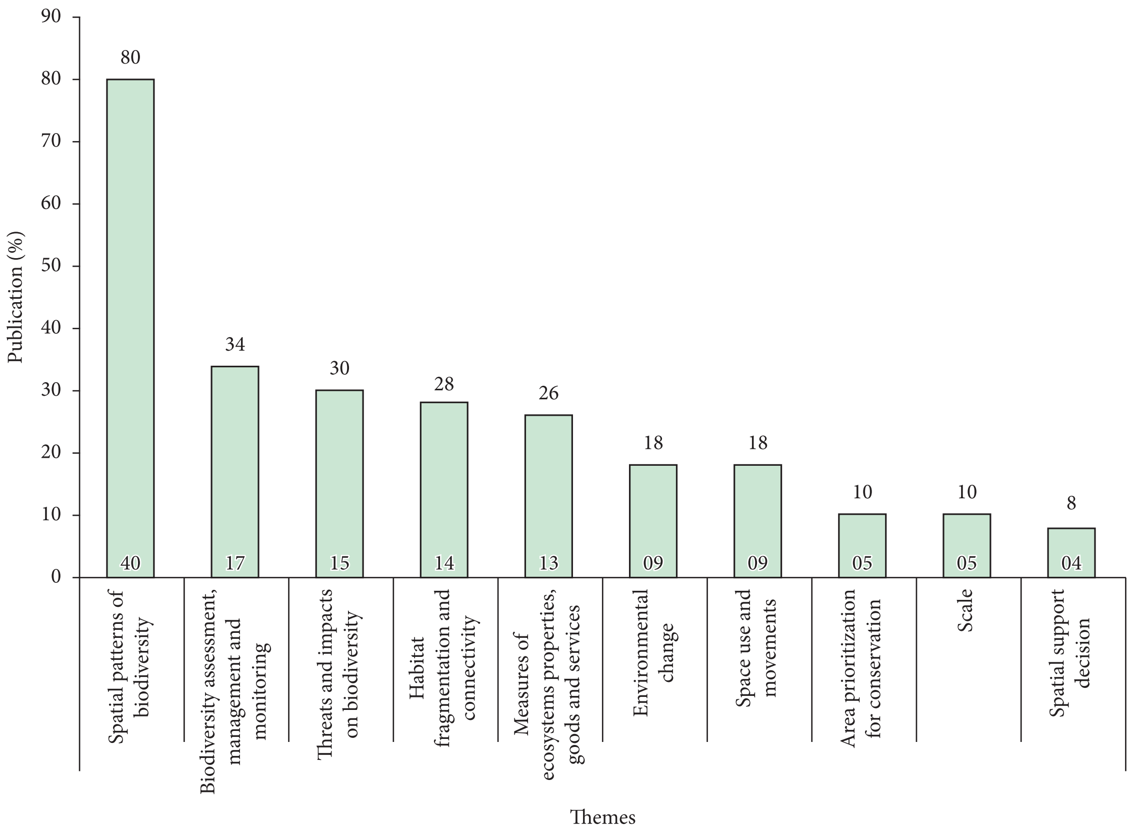

Figure 8. Top Top 10 research themes addressed by the 50 most cited articles recently published in the topics "Conservation GIS & Spatial Analysis", over the last three years (2008-2010). The number of articles is given inside the columns.

It is noteworthy to emphasize that the overview presented here about publication on Conservation GIS and Spatial Analysis is not a comprehensive review of this burgeoning field. Possible limitations in our scientometric analysis include the overestimation of the scientific production on the target topics, derived from commission errors that happen, for example, when we retrieved papers that included the search keywords in their abstracts just to contextualize their results according to these themes, although did not directly address these issues. On the contrary, other limitation would be the sub estimation of scientific production on the analyzed fields, resulting from omission errors that occur when papers addressing the target issues, but that did not explicitly mentioned the search keywords, were not retrieved from database. Indeed, the last situation occurred at least with some papers that should have been included in the analysis but were not retrieved in the searches (*e.g.* Ribeiro *et al.* 2009; Grelle *et al.* 2010). In addition, as we not included "landscape ecology" among the search keywords, it is possible that many publications had been omitted from the analysis.

To conclude, we known that our planet is changing fast. Scientists have raised concerns that we are entering into a new geological epoch named the Anthropocene in which human impacts on our biological systems and biogeochemical cycles significantly dominate natural processes (Crutzen 2002; Zalasiewicz *et al.* 2008, 2010; Skidmore *et al.* 2011). Fortunately, geospatial technologies have radically transformed our ability to detect, map, and model such changes, expanding our capability to monitor and assess biodiversity systems (Scholes *et al.* 2008; Horning *et al.* 2010; Skidmore *et al.* 2011; Cagnacci *et al.* 2010). On the other hand, recent advancements in spatial ecology can allow us to put these data in the context of our ecological understanding and to generalize these patterns to advance ecological theories and their applications (Recknagel 2003; Green *et al.* 2005; Olden *et al.* 2006; Skidmore *et al.* 2011; Cagnacci *et al.* 2010). In combination, these fields can provide a powerful instrumentation to conservation researchers and practitioners. We hope that this "Conservation GIS and Spatial Analysis" Special Issue in *N&C* can be a fine contribution to promote this synergy and to stimulate the capacity building on this field, especially in megadivese countries like Brazil.

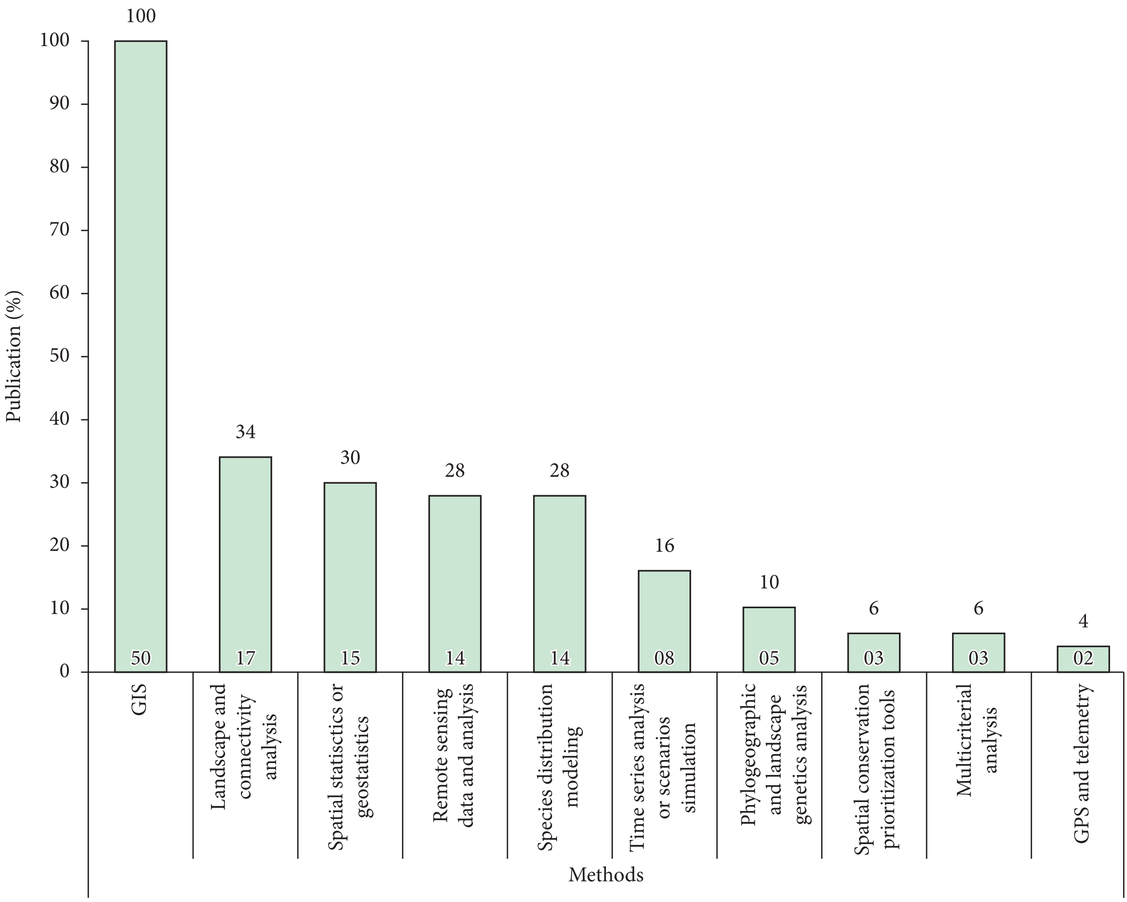

Figure 9. Top 10 methods employed by the 50 most cited articles recently published in the topics "Conservation GIS & Spatial Analysis", over the last three years (2008-2010). The number of articles is given inside the columns.

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