Antarctic Ecology One Century after the Conquest of the South Pole: How Much Have We Advanced?

IAN S. ACUÑA-RODRÍGUEZ, ERNESTO GIANOLI, FERNANDO CARRASCO-URRA, GISELA C. STOTZ, CRISTIAN SALGADO-LUARTE, RODRIGO S. RIOS, AND MARCO A. MOLINA-MONTENEGRO

The knowledge derived from Antarctic ecology may be fundamental for facing the complex environmental future of the world. As an early-warning system, a deep understanding of Antarctic ecosystems is therefore needed, but Antarctic ecology as a field is still very young and currently under consolidation. Around the world, 55 nations are involved in this task through their research programs, and, considering the importance of this joint effort, we evaluate some basic trends of their publications through a wide bibliographical review of Antarctic ecology. All ecology-related Antarctic papers published for 106 years (1904–2010) were reviewed. A lack of population and ecosystem research was observed, even in Animalia, the most studied kingdom. The publications originated mainly in developed countries; however, emerging countries have increased their participation in recent years. The current trends of Antarctic ecology as a field show a constant but low representation in both Antarctic science and ecology.

Keywords: Antarctic ecology, scientific publications, Antarctic research, international territorial administration, Web of Science

From the time of the extensive hunting of marine species to the development of the Antarctic tourism industry in the late 1980s, humans' presence south of the 60-degree south (°S) parallel has had an inevitable impact (Tin et al. 2014). However, despite the serious alterations of our direct interaction with Antarctica, the main threat to its ecology seems to be the global change process that we are driving now (Turner et al. 2013, Tin et al. 2014).

A geographic convergence of ecological extremes occurs in both Arctic and Antarctic regions, but because of the presence of a continental plate and a major biogeographic barrier around it, in Antarctica, some environmental factors reach their global maxima (Bergstrom et al. 2006, Cassano 2013). Its ecological stability is certainly based on the strong levels of isolation and biotic exclusion that these conditions confer (Convey et al. 2013). A common perception among people about Antarctic environments is that they are climatically rough—and, indeed, they are—but these harsh conditions do not imply an inherent ecological resistance to human effects on global processes; the Antarctic continent was actually the place where the detection of these effects began (Vaughan and Doake 1996). For example, some plants have already colonized the Antarctic region, particularly the subantarctic islands (Frenot et al. 2005). Accelerated climate change (a temperature increase of over 0.11 degrees Celsius per decade in the last 50 years in parts of the Antarctic Peninsula) and greater human activity are increasing the number, extent, and effects of nonnative species on Antarctic ecosystems (Molina-Montenegro et al. 2012, 2014).

Unfortunately, some of the fears about the stability of global dynamics that researchers have had for the last 30 years are apparently coming true and faster than was expected (Vaughan et al. 2003, Meredith and King 2005, Bergstrom et al. 2006, Aronson et al. 2011). Ancient landscapes are emerging from melted ice shelves on the Antarctic Peninsula (Pritchard et al. 2012), and the demography of several coastal species is being altered (Stokstad 2007, Barbraud et al. 2012). Although the expected impact of global change on Antarctica is smaller than that expected for the Arctic (Kennedy 1995), there is a lack of long-term studies supporting this idea. Recent research (Moline et al. 2004, IPCC 2013) suggests that the effects of major change (e.g., climate change, biological invasions) on the Antarctic Peninsula and Antarctic islands have been underestimated. Current climatic models for polar latitudes of the Southern Hemisphere—in particular, for the coastal zones of mainland Antarctica—predict an increase in atmospheric nitrogen deposition and a rise in temperature, which is expected to cause an increase in cloudiness and precipitation (IPCC 2013). This landscape change also makes coastal ecosystems and their populations more accessible and vulnerable to anthropogenic effects—mainly those generated by fisheries

BioScience 64: 593–600.
doi:10.1093/biosci/biu074 Advance Access publication 11 June 2014

and tourism (Chown et al. 2012, Forcada et al. 2012). In addition, scientific expeditions could be another important factor of disturbance, because they remain in one place much longer than do tourists, continuously affecting the environment around the station, and bring in large quantities of supplies and equipment that may be contaminated with soil and organic material (e.g., Chwedorzewska and Korczak 2010, Chown et al. 2012, Molina-Montenegro et al. 2014). Moreover, the ecological thresholds of Antarctic species lie in the extreme of the distributional gradient, which makes them very susceptible to small changes; for this reason, the entire Antarctic ecosystem is now highly vulnerable (Peck et al. 2004, Clarke et al. 2007, Somero 2010).

For this reason, it is urgent that environmental knowledge of Antarctica be consolidated if we expect to solve the challenges of the current global change scenario, but this would imply the compilation of enough information from Antarctic ecosystems to model complex responses (Convey 2011, Wall et al. 2011, Rogers et al. 2012). This is a huge task if we consider that at least half of the extant Antarctic species are thought to be undiscovered (Griffiths 2010, Schiapirelli and Hopcroft 2011). Now, given that ecological knowledge is the basis for any sustainable administration and that the current changes in global dynamics are negatively affecting the Antarctic continent, the study of Antarctic ecology should arise both as a research area for governments and institutions and as an academic topic of universities and individual ecologists around the world. Nevertheless, Antarctic research is too expensive for the majority of national science foundations, and therefore, many proposals are not funded, despite the issue's being one of great importance. Although seminal explorations have improved the knowledge about this continent, there is still much to do; knowing how far we have advanced could be a first step toward accomplishing this goal.

Here, we present a baseline characterization of a century of Antarctic ecological knowledge, in an attempt to identify the main thematic and socioeconomic trends in ecological research that has been performed in Antarctica. We also want to determine who is actually contributing to Antarctic ecological research in both absolute (i.e., the number of papers) and relative terms, when certain economic and logistic variables are taken into account. Finally, we explore the percentage of Antarctic ecology articles in the full set of ecological publications and in the subset of Antarctic science publications. We reviewed and analyzed peer-reviewed scientific papers to integrate the available knowledge and to identify historical trends in order to move forward in Antarctic ecology.

We used the Thomson Reuters Web of Science to cover 106 years of publications (1904–2010). We used the following topic keywords: *antarctic*, *antarctica*, *antartica*, and *antartida*, within ecology-related subject categories (i.e., ecology, biodiversity and conservation, and evolutionary biology). We openly recognize that Antarctic ecological literature is, in fact, broader than that found in the Web of Science, particularly during the beginnings of Antarctic literature. Nonetheless, the peer-reviewed publications contained in the Web of Science database certainly include most current studies and have passed an adequate quality filter. We verified that the Antarctic link to each publication was not casual (i.e., as a result of common or scientific names) or indirect (from subantarctic studies). For the latter, we considered as true Antarctic papers those whose research was performed within the geographic limits of the Antarctic region as defined in *The Antarctic Treaty*; that is, the world located south of the 60°S parallel (Conference on Antarctica 1959).

Data organization and analysis

Two thematic variables were extracted from the content of the papers: the taxonomic kingdom of the studied organism (i.e., Prokariota, Protista, Fungi, Plantae, or Animalia) and the biotic level of organization (i.e., organism, population, community, or ecosystem). The paper's nationality was assigned on the basis of the affiliations of the authors; the 55 countries identified were divided into six regions (i.e., Africa, Asia, Europe, Latin America and the Caribbean, North America, and Oceania) in order to compare them in terms of their absolute and relative contributions over time.

For the socioeconomic analysis, we used those countries with more than 1% participation in Antarctic ecological publications (21), classified by their development status, which was based on the Human Development Index (HDI). The corresponding level was defined by the percentile range in which each national HDI value falls: Those below the 50th percentile were categorized as *developing* countries; between the 50th and 80th percentiles were *emerging* countries; and those above the 80th percentile were categorized as *developed* countries. The percentiles were based on the distribution of the 187 national HDI values as described in the Human Development Report (UNDP 2011). The relative contribution of each socioeconomic group was analyzed on the basis of the last 20 years of our database (1990–2010), a period in which a continuous exponential trend in the number of published papers on Antarctic ecology appears to exist. We also considered a reduced time window (i.e., the last 10 years of data: 2000–2010) to explore the most recent trends. In addition, we analyzed the relative contribution of Antarctic ecology as a research field to the total indexed ecology-related publications (ecological subject categories of the Web of Science), as well as the percentage of ecological papers that were on Antarctic science *sensu lato* for the 1991–2011 period.

Finally, we used the number of papers and their associated *h*-index (Hirsch 2005) accumulated up to the year 2010 to compare the impact of the Antarctic ecological research among different countries. In addition, we explored the efficiency of each country in terms of the relationship of this impact with the amount of its public investment in Antarctic ecology, in absolute terms, as well as with the individual cost of each Antarctic ecological publication. For this purpose, we analyzed data from the United Nations Educational, Scientific and Cultural Organization (UNESCO) Institute

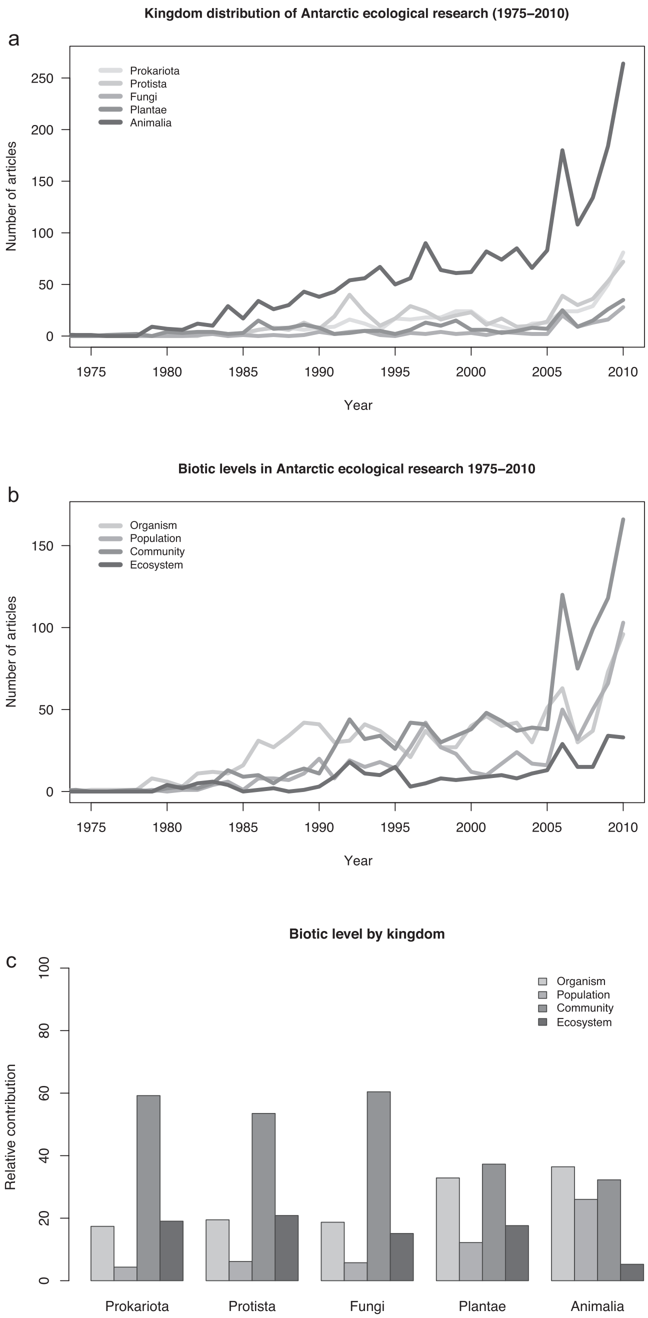

Figure 1. Historical trend of Antarctic ecological publications (as the percentage contribution) as a function of (a) the kingdom and (b) the level of biological organization and (c) the distribution of articles as a function of the biological organization level in each kingdom.

for Statistics (UNESCO 2012) and from the World Bank DataBank (World Bank 2014).

As a proxy for the national investment in science, we used the 2009 gross domestic expenditure on research and development (GERD) as reported by UNESCO (2012). These data include five sources of funding: government, business enterprise, higher education, nonprofit, and foreign. Our analysis included three categories that could be assumed to be the public investment in research and development, leaving out funding from business enterprises and foreign sources. To estimate the investment in Antarctic ecology research, we calculated the percentage of Antarctic ecological papers in 2009 of each nation among their total number of papers published for the same year, as determined through our Web of Science search, and used that percentage to obtain the specific amount of investment in Antarctic ecology for each country from each national public GERD, assuming equivalence between the percentage of articles and the percentage of investment.

Significant trends were tested with regression analyses. The regional and thematic categorizations were not mutually exclusive, so the categorical percentages may sum to more than 100%; the socioeconomic data were log transformed to fit the linearity assumption. The analyses were conducted and graphs created using the R statistical environment (version 2.15.2; R Foundation for Statistical Computing, Vienna, Austria).

The first ecological article from the database related to Antarctica appeared in the journal *Evolution* (Marshall 1953). Since then, 3185 articles were published up to 2010, but after Marshall's (1953) paper, the presence of Antarctic studies in ecological journals (at least the indexed ones) was discontinuous and scarce for some years. Only after 1974 was at least one article per year published in this field (supplemental table S1). Antarctic ecological research began to be present in the scientific literature after some years of slow but continuous growth (1975–1989), finally reaching an exponential increase from 1990 to 2010.

Resulting thematic trends

Animalia has prevailed as the most studied kingdom in Antarctica. Moreover, the difference between Animalia and the other kingdoms has increased over time (figure 1a). The frequency of studies on other life forms was low and relatively constant until 2005, when a general increase in publications occurred for all kingdoms. Despite the trend, differences are clear: Animalia was the most studied by far, and, for the rest, there was some divergence between the pairs Prokaryota–Protista and Plantae–Fungi (figure 1a). Furthermore, in Antarctic ecological research, the main level of biological organization was still the organism; it was the most popular level, with 38.3% of all papers and 41.7% of publications in 2010 (figure 1b). A shortage of ecosystem studies was evident; in 2010, they represented only 8.3% of Antarctic ecological publications. The distribution of publications among organizational levels was not the same for all kingdoms (figure 1c). The dominance of community-based studies was clear in Prokaryota, Protista, and Fungi, as was their lack of population research. In Plantae, organism and community publications were similarly represented, but the community-level studies were still more prevalent. For Animalia, the kingdom with the most publications, the lack of ecosystem-level studies contrasted with the similar numbers among the three remaining levels of biological organization (figure 1c).

Table 1. Regional participation in Antarctic ecological research.

Region	Number of countries	Number of papers per region: Mean	Standard deviation	Year of continuous publication	Annual publication rate: Mean	Standard deviation
Europe	25	1869	51.6	1975	21.8	5.1
North America	2	680	18.8	1980	7.1	4.3
Oceania	3	512	14.1	1986	9.4	3.2
Latin America and the Caribbean	10	265	7.3	1990	7.5	2.7
Asia	13	230	6.3	1988	5.4	2.8
Africa	2	70	1.9	2005	2.5	2.2

Note: The year of continuous publication is that in which the region began to publish at least one paper per year. The annual publication rate was calculated as the geometric mean and standard deviation of papers per year.

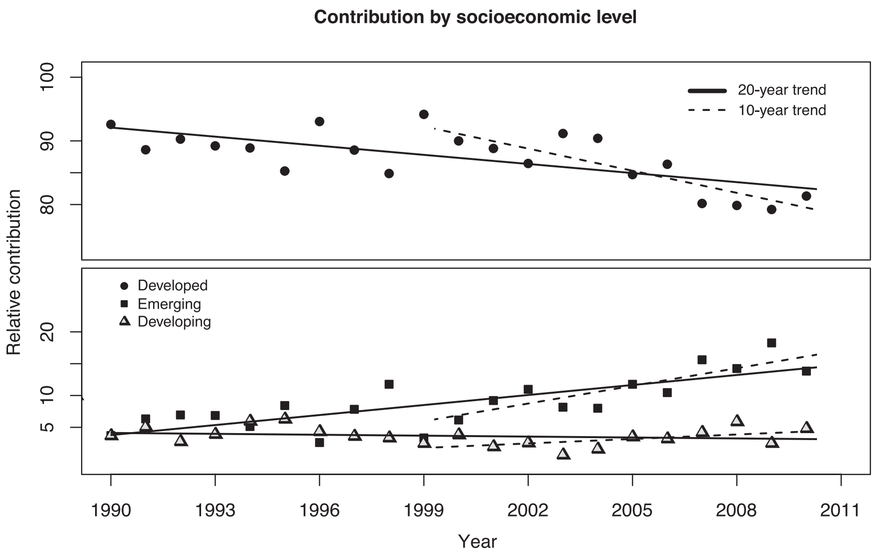

Figure 2. Relative historical contribution trend (as the percentage of publications) during the last 20 years (the continuous line) and during the last 10 years (the dashed line) represented by our data among socioeconomic groups. Statistics: developed countries, 1990–2010 slope = –0.47, standard deviation (SD) = 0.12, r^2 = .42, p ≤ .001; emerging countries, 1990–2010 slope = 0.53, SD = 0.09, r^2 = .59, p ≤ .001; developed countries, 2000–2010 slope = –1.16, SD = 0.24, r^2 = .68, p ≤ .001; emerging countries, 2000–2010 slope = 0.92, SD = 0.20, r^2 = .66, p = .001.

Resulting regional and socioeconomic trends

Overall, the average number of countries per publication was surprisingly low (1.36, standard deviation [SD] = 0.71). In other words, 2312 articles—72.6% of all Antarctic papers until 2010—were written by authors at one institution or at institutions of the same nation. Among the regions, Europe had by far the highest historical scientific productivity in Antarctic ecology (table 1) but also had more countries than did the other regions, such as North America or Oceania. European institutions were represented in 69.2% of the papers published in 2010, although all of the regional publication numbers were highly influenced by the productivity of just a few countries (table S1). The United Kingdom and Germany were represented in 56% of their region's papers; Italy, Spain, and France were also frequent contributors and appeared in 33.7% of the European articles, but the remaining 20 countries had a joint participation of only 12.1%. South Africa accounted for 98.5% of the African papers. Likewise, Oceania, Australia and New Zealand contributed 99.5% of the Antarctic ecological publications. In Latin America, Argentina, Brazil, and Chile accounted for almost 95% of the publications (55.7%, 19.4%, and 19.4%, respectively). For Asia, Japan and China stand out, with 44.6% and 20.8% of the contributions, respectively. Globally, five countries accounted for three-quarters of the Antarctic ecological articles: the United Kingdom (19.8%), the United States (18.6%), Germany (16.4%), Australia (10.7%), and Italy (8.73%). Over half of the countries included in this review contributed less than 1% (31 articles) of the publications (table S1).

Historically, the developed countries have been responsible for more than 85% of the publications, whereas the emerging and developing countries have contributed modestly. However, the analysis of our last 20 years of data reveals that the relative participation of the developed countries has been reduced, whereas the relative contribution of the emerging nations increased, a tendency that became more evident during the last decade in the database (figure 2). In the recent panorama of Antarctic ecology, despite a great increase in the number of publications over our last 20 years of data, their relative contribution to the whole body of indexed ecological literature was still low (3.75%, SD = 0.41) and remained quite stable (figure 3a). Something similar occurred in Antarctic science, in which ecology represented only, on average, 10.5% (SD = 1.08) of the publications (figure 3a); however, with

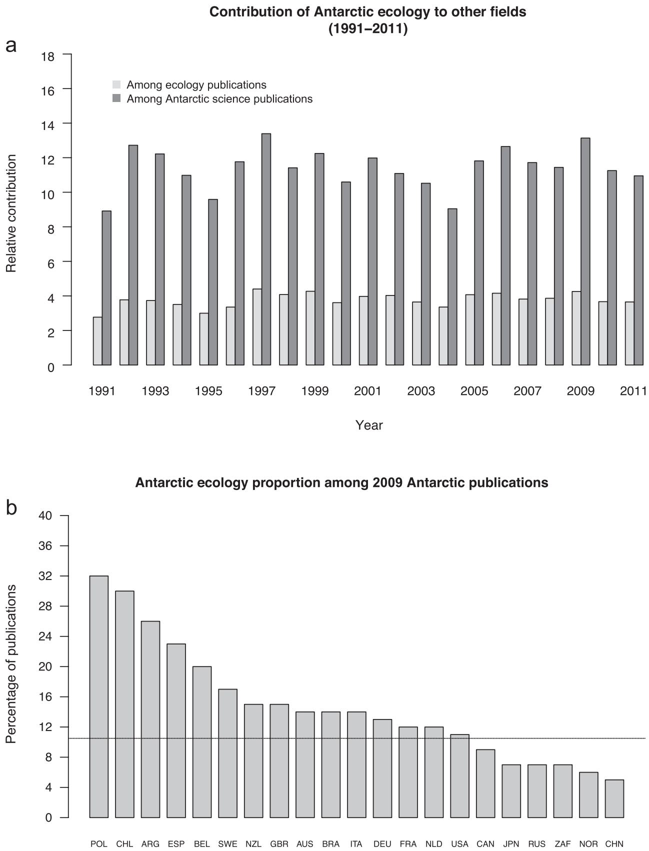

Figure 3. (a) The annual percentage (1991–2011) of Antarctic ecology papers among all ecological publications in the Web of Science (the dark gray bars) and among the Antarctic science literature (the light gray bars). (b) The percentage of each nation's Antarctic publications devoted to ecology for 2009; the line represents the mean percentage of ecology papers among the Antarctic science publications between 1991 and 2011. Abbreviations: ARG, Argentina; AUS, Australia; BEL, Belgium; BRA, Brazil; CAN, Canada; CHL, Chile; CHN, China; DEU, Germany; ESP, Spain; FRA, France; GRB, the United Kingdom; ITL, Italy; JPN, Japan; NLD, the Netherlands; NOR, Norway; NZL, New Zealand; POL, Poland; RUS, Russia; SWE, Sweden; USA, the United States; ZAF, South Africa.

respect to Antarctic research in ecology, the countries were represented very differently; for example, in 2009, a quarter of the Antarctic publications of Poland, Chile, and Argentina were on ecology, but less than 8% of those of China, Norway, Japan, Russia, and South Africa were (figure 3b).

Although the United Kingdom historically participated in more publications on Antarctic ecology than did any other country, in the more recent years, the leadership in this field shifted to the United States. The 2009 GERD comparison shows the large differences in investment between the United States and other countries, even developed ones; as was expected, this correlates positively with the number of papers and the impact of the research (figure 4a). However, the positive correlation between monetary investment and impact was not present when the average cost and impact of each article was analyzed (figure 4b); instead, the same average impact was achieved with very different levels of investment, and, surprisingly, China and South Africa—the only two developing countries in this analysis—stand out, together with Norway.

Conclusions

Considering the number of papers published on each kingdom, Animalia was by far the taxonomic group with the highest number—more than that of all other kingdoms considered together. This could be the result of the relatively high number of marine animal species found in Antarctic ecosystems (De Broyer et al. 2011, Rogers et al. 2012) and is certainly because of the economic interest in some of them (Phillips and Wood 2009, Nicol et al. 2012). With regard to publications at the different levels of biological organization, the lack of ecosystem research was evident across all kingdoms (figure 1b, 1c). A similar deficiency was observed in population studies, especially for Protista, Prokaryota, and Fungi (figure 1c). The popularity of studies at the community level (38%) was probably related to its association with biodiversity indexes. For example, Wall (2005) correctly indicated that we have failed to acknowledge the impact of different components of global change on biodiversity and the process at community and ecosystem levels. In addition, she pointed out that we cannot measure the effect of global change on terrestrial biodiversity if we underestimate the contribution of different communities such as those from the Antarctic soils. The current context of global change demands emphasis on other research questions, such as the particular demographic processes of local populations and metapopulations (Dugger et al. 2010) or the functional responses of species to existing or novel pressures (Forcada et al. 2012, Molina-Montenegro et al. 2012).

Important actions have been taken in this regard—for example, by the Scientific Committee on Antarctic Research (SCAR)—to generate, organize, and share large amounts of ecological information on Antarctic species. Programs and scientific initiatives such as the Census of Antarctic Marine Life, Evolution and Biodiversity in Antarctica, SCAR's *Antarctic Climate Change and the Environment* report, and the Antarctic Nearshore and Terrestrial Observing System are good examples. Examples of successful long-term scientific programs are those conducted in the McMurdo Dry Valleys, where different surveys have been maintained for decades at many biological scales, which has enhanced the knowledge of Antarctic biodiversity (Wall 2005). The availability of these data will certainly promote research at the ecosystem level and in other underrepresented areas of research.

Around the world, researchers and managers in both political and academic organizations are working to maintain the interests of their nations and institutions in Antarctic research. A remarkable effort has been made, particularly by developed countries, which today generate 85% of Antarctic ecological publications; despite this large contribution, their annual

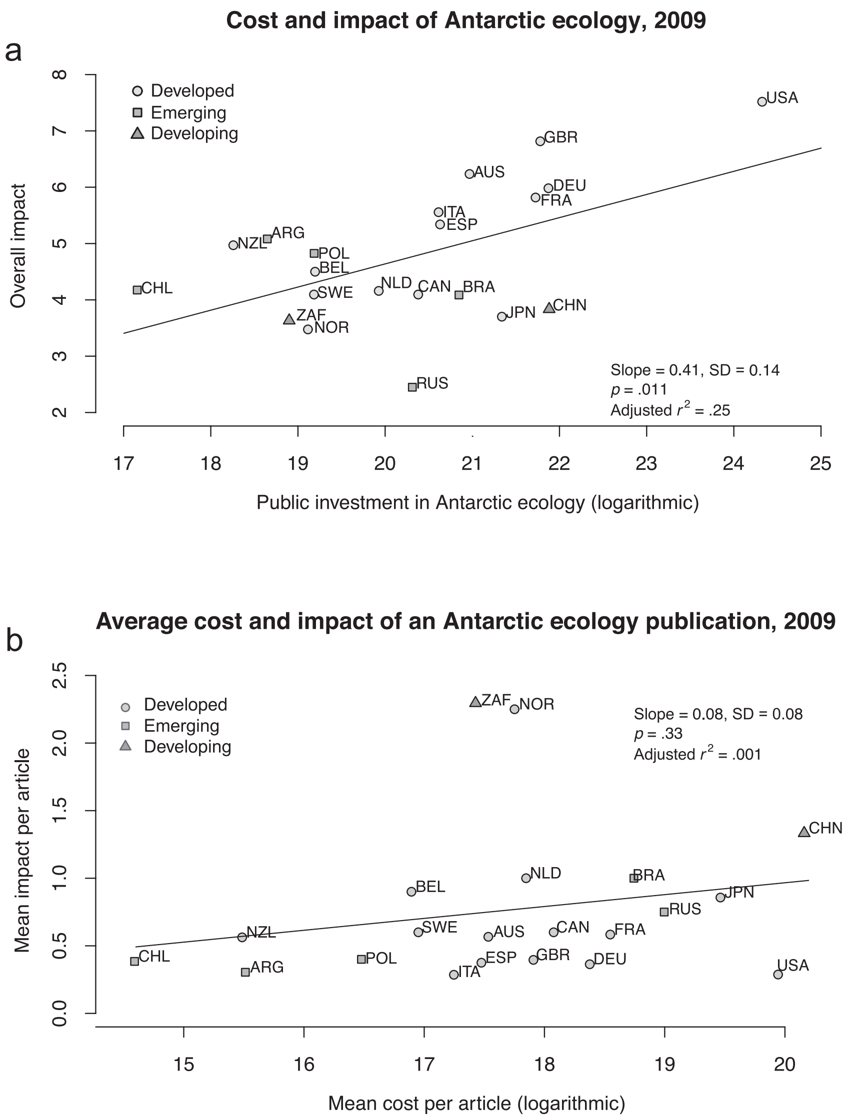

*Figure 4. The correlation (a) between the total budget for Antarctic ecology as a function country and the associated impact (the number of articles × **h**-index) of its publications and (b) between the average cost (in US dollars) of an article and the mean **h**-index as a function of country. The amount of the public investment in Antarctic ecological research was derived from the 2009 gross expenditure on research and development. Abbreviations: ARG, Argentina; AUS, Australia; BEL, Belgium; BRA, Brazil; CAN, Canada; CHL, Chile; CHN, China; DEU, Germany; ESP, Spain; FRA, France; GRB, the United Kingdom; ITL, Italy; JPN, Japan; NLD, the Netherlands; NOR, Norway; NZL, New Zealand; POL, Poland; RUS, Russia; SWE, Sweden; USA, the United States; ZAF, South Africa.*

relative participation is decreasing (figure 2). Considering that Antarctic research is particularly expensive and logistically demanding, this decrease, although it is slight, is not a good sign for the future of Antarctic ecology. For this not-well-known continent, every article has great value in terms of its relative contribution to the consolidation of knowledge needed to face the challenges of current global change (Convey 2011), but the percentage of Antarctic papers among all ecological publications has not increased with time; in fact, it has remained below 4% (figure 3a), which could regrettably represent our commitment as ecologists to Antarctica. There was a small but significant increasing trend in the relative participation of emerging countries in the Antarctic ecological literature (figure 2), which certainly contributes to maintaining this modest presence of Antarctic ecology in the scientific literature.

In Antarctic science, ecology research was better represented (10.5% of the Antarctic papers; figure 3a), but this is still a low percentage if we consider perhaps the most interesting aspect about Antarctica—that nobody has (still) ever lived there permanently. In a wide sense, this is the only place where the human factor could be controlled; for ecological research, this is priceless, but it is becoming less true over time (Bergstrom et al. 2006, Aronson et al. 2011, Pritchard et al. 2012). Even without establishing roads or cities there, we are already affecting Antarctic ecosystems because of our broader environmental behavior.

Furthermore, beyond its ecological uniqueness, this continent also has a particularly complex socioeconomic feature: its international administration. In this context, the scientific effort of a nation determines its participation in the decision making for Antarctica (Conference on Antarctica 1959, Pannatier 1994). It is curious that, in contrast with its international administration, Antarctic ecological publications are mainly produced without international collaboration (73%)—a fact that certainly does not reflect the international collaborative spirit that was invoked during the Conference on Antarctica but that definitively gives much value to the current international initiatives that are working for the knowledge of this continent.

An estimation of the significance of the Antarctic scientific effort of a country is urgently needed, but it is not just a question of absolute numbers; depending on the methodology, different results could be obtained (Dudeney and Walton 2012). We suggest that ecological knowledge should be the priority, because it provides the basic tools for the sustainability of any other activities, whether they be logistical, exploratory, investigative, or productive. Antarctica is certainly the continent with the least-known ecosystems in the world, a place in which the first descriptions of some of its biotic communities are currently being performed (Bowden et al. 2011). But, in a typical year, more than 380,000 visitors (tourists, staff, and crew) cross the Antarctic Circle; 290,000 are tourists, and a third of them land and walk through the south polar ecosystems (IAATO 2012), with an associated environmental risk (Lewis et al. 2005, Hughes et al. 2010, 2011, Chown et al. 2012).

Differences in resources and technological capacities are evident among nations, which makes the direct comparison of the number of articles a poor indicator of a nation's effort in Antarctic science (Dudeney and Walton 2012). This may be observed for Antarctic ecology, as well, as the positive correlation of the budgets for this research and the number and impact of each country's publications show (figure 4a). But some countries are more effective in terms of transforming that money into academic impact; despite the great differences among nations in the average cost of a single paper on Antarctic ecology, this is not correlated with its average *h*-index (figure 4b). A stunning effectiveness relative to the group is achieved by the only two developing countries (South Africa and China), as well as by Norway, a developed nation. Similarly, the most economic articles (those from Chile, New Zealand, Argentina, and Poland) have the same or a greater average impact than do papers from nations with a greater investment per article, such as Italy, the United States, and Germany (figure 4b). The Netherlands, Brazil, and Belgium also stand out from the average but with very different costs.

Some important aspects, such as the proximity to Antarctica and the possession of Antarctic facilities, may affect the cost of Antarctic research. It is also true that some questions in ecology require enormous amounts of money to answer, and that kind of research comes mainly from developed nations. The positive correlation between the complete budget for Antarctic ecology, derived from the 2009 GERD, and its joint impact, along with the lack of correlation with their average values, probably shows different moments of each national Antarctic ecological initiative; countries with historically massive Antarctic programs are capable of financing a wider variety of research at different academic levels, in contrast to emerging or developing countries, in which fewer resources are concentrated in specific research lines in order to logically maximize the operational result of public science: the impact of publications.

Today, despite the great improvement in our knowledge about the Antarctic continent and the continuous human presence on the mainland for several decades, issues concerning Antarctica still remain within the scope of scientific curiosities for most people, and the diverse opinions arise in the public perception about its future (Liggett and Hemmings 2013, Tin et al. 2014). We are now facing the urgent need to know how the Antarctic ecological system works, and it seems that our actual research effort is far from sufficient for this purpose (Chown and Convey 2007, Convey 2011).

A joint analysis of the data will allow us to confront ecological processes across different spatiotemporal scales (Wall et al. 2011), which is necessary for resource management and decisionmaking because of the interactive nature of ecological factors (Chown et al. 2012, Galli et al. 2012). Therefore, future Antarctic ecological research should be focused at the population and ecosystem levels of biological organization and should also systematically address terrestrial ecological phenomena because of the rapid change in landscape features, particularly on Antarctic shores. As the major human actors, tourists must become involved in research activities, such as recording and reporting data (e.g., georeferencing photographs of populations). The best outcome for Antarctic conservation is not only for tourists to return home without a physical souvenir but for them to collaborate in the accumulation of Antarctic ecological knowledge.

Finally, a complex issue for future Antarctic administration arises as different types of activities are proposed for Antarctica (Tin et al. 2014). It is necessary to clarify the terms in which *The Antarctic Treaty* defines the research participation of nations, and we suggest that it is also fundamental to incorporate into this new approach more equitable formulas for the estimation of each nation's research effort, in which Antarctic ecology should have a special place.

Acknowledgments

Thanks to three anonymous reviewers, whose comments helped improve the quality and clarity of this study. This article is a contribution of Scientific Committee on Antarctic Research's AnT-ERA (Antarctic Thresholds: Ecosystem Resilience and Adaptation) program.

Supplemental material

The supplemental material is available online at *http://bioscience.oxfordjournals.org/lookup/suppl/doi:10.1093/biosci/biu074/-/DC1*.

References cited

Aronson RB, Thatje S, McClintock JB, Hughes KA. 2011. Anthropogenic impacts on marine ecosystems in Antarctica. Annals of the New York Academy of Sciences 1223: 82–107.

Barbraud C, Rolland V, Jenouvrier S, Nevoux M, Delord K, Weimerskirch H. 2012. Effects of climate change and fisheries bycatch on Southern Ocean seabirds: A review. Marine Ecology Progress Series 454: 285–307.

Bergstrom DM, Convey P, Huiskes AHL, eds. 2006. Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator. Springer.

Bowden DA, Schiaparelli S, Clark MR, Rickard GJ. 2011. A lost world? Archaic crinoid-dominated assemblages on an Antarctic sea mount. Deep Sea Research II 58: 119–127.

Cassano JJ. 2013. Climate of extremes. Pages 102–136 in Walton DWH, ed. Antarctica: Global Science from a Frozen Continent. Cambridge University Press.

Chown SL, Convey P. 2007. Spatial and temporal variability across life's hierarchies in the terrestrial Antarctic. Philosophical Transactions of the Royal Society B 362: 2307–2331.

Chown SL, et al. 2012. Challenges to the future conservation of the Antarctic. Science 337: 158–159.

Chwedorzewska KJ, Korczak M. 2010. Human impact upon the environment in the vicinity of Arctowski Station, King George Island, Antarctica. Polish Polar Research 31: 45–60.

Clarke A, Johnston NM, Murphy EJ, Rogers AD. 2007. Antarctic ecology from genes to ecosystems: The impact of climate change and the

importance of scale. Philosophical Transactions of the Royal Society B 362: 5–9.
Conference on Antarctica. 1959. The Antarctic Treaty. Secretariat of the Antarctic Treaty. (16 April 2014; *www.ats.aq/e/ats.htm*)
Convey P. 2011. Antarctic terrestrial biodiversity in a changing world. Polar Biology 34: 1629–1641.
Convey P, Brandt A, Nicol S. 2013. Life in a cold environment. Pages 161–210 in Walton DWH, ed. Antarctica: Global Science from a Frozen Continent. Cambridge University Press.
De Broyer C, et al. 2011. How many species in the Southern Ocean? Towards a dynamic inventory of the Antarctic marine species. Deep Sea Research II 58: 5–17.
Dudeney JR, Walton DWH. 2012. Leadership in politics and science within the Antarctic Treaty. Polar Research 31 (art. 11075).
Dugger KM, Ainley DG, Lyver PO'B, Barton K, Ballard G. 2010. Survival differences and the effect of environmental instability on breeding dispersal in an Adélie penguin meta-population. Proceedings of the National Academy of Sciences 107: 12375–12380.
Forcada J, Trathan PN, Boveng PL, Boyd IL, Burns JM, Costa DP, Fedak M, Rogers TL, Southwell CJ. 2012. Responses of Antarctic pack-ice seals to environmental change and increasing krill fishing. Biological Conservation 149: 40–50.
Frenot Y, Chown SL, Whinam J, Selkirk PM, Convey P, Skotnicki M, Bergstrom DM. 2005. Biological invasions in the Antarctic: Extent, impacts and implications. Biological Review 80: 45–72.
Galli A, Wiedmann T, Ercin E, Knoblauch D, Ewing B, Giljum S. 2012. Integrating ecological, carbon and water footprint into a "footprint family" of indicators: Definition and role in tracking human pressure on the planet. Ecological Indicators 16: 100–112.
Griffiths HJ. 2010. Antarctic marine biodiversity: What do we know about the distribution of life in the Southern Ocean? PLOS ONE 5 (art. e11683).
Hirsh JE. 2005. An index to quantify an individual's scientific research output. Proceedings of the National Academy of Sciences 102: 16569–16572.
Hughes KA, Convey P, Maslen NR, Smith RIL. 2010. Accidental transfer of non-native soil organisms into Antarctica on construction vehicles. Biological Invasions 12: 875–891.
Hughes KA, et al. 2011. Food for thought: Risks of non-native species transfer to the Antarctic region with fresh produce. Biological Conservation 144: 1682–1689.
[IAATO] International Association of Antarctica Tour Operators. 2012. Tourism Statistics. IAATO. (16 April 2014; *www.iaato.org/es/tourism-statistics*)
[IPCC] Intergovernmental Panel on Climate Change. 2013. Climate Change 2013: The Physical Science Basis. IPCC. (25 January 2013; *www.ipcc.ch/report/ar5/wg1*)
Kennedy AD. 1995. Antarctic terrestrial ecosystem response to global environmental change. Annual Review of Ecology and Systematics 26: 683–704.
Lewis PN, Riddle MJ, Smith SDA. 2005. Assisted passage or passive drift: A comparison of alternative transport mechanisms for non-indigenous coastal species into the Southern Ocean. Antarctic Science 17: 183–191.
Liggett D, Hemmings AD, eds. 2013. Exploring Antarctic Values: Proceedings of the Workshop *Exploring Linkages between Environmental Management and Value Systems*: The Case of Antarctica. University of Canterbury. Gateway Antarctica Special Publication no. 1301.
Marshall NB. 1953. Egg size in Arctic, Antarctic and deep-sea fishes. Evolution 7: 328–341.
Meredith MP, King JC. 2005. Rapid climate change in the ocean west of the Antarctic Peninsula during the second half of the 20th century. Geophysical Research Letters 32 (art. L19604).
Molina-Montenegro MA, Carrasco-Urra F, Rodrigo C, Convey P, Valladares F, Gianoli E. 2012. Occurrence of the non-native annual bluegrass on the Antarctic mainland and its negative effects on native plants. Conservation Biology 26: 717–723.
Molina-Montenegro MA, Carrasco-Urra F, Acuña-Rodríguez IS, Oses R, Torres-Díaz C, Chwedorzewska KJ. 2014. Assessing the importance of human activities for the establishment of the invasive *Poa annua* in the Antarctica. Polar Research. Forthcoming.
Moline MA, Claustre H, Frazer TK, Schofield O, Vernet M. 2004. Alteration of the food web along the Antarctic Peninsula in response to a regional warming trend. Global Change Biology 10: 1973–1980.
Nicol S, Foster J, Kawaguchi S. 2012. The fishery for Antarctic krill: Recent developments. Fish and Fisheries 31: 30–40.
Pannatier S. 1994. Acquisition of consultative status under the Antarctic Treaty. Polar Record 30: 123–129.
Peck LS, Webb KE, Bailey DM. 2004. Extreme sensitivity of biological function to temperature in Antarctic marine species. Functional Ecology 18: 625–630.
Phillips K, Wood R. 2009. Antarctic waters fishery. Pages 342–348 in Wilson D, Curtotti R, Begg G, Phillips K, eds. Fishery Status Reports 2008: Status of Fish Stocks and Fisheries Managed by the Australian Government. Australian Government Department of Agriculture, Fisheries and Forestry.
Pritchard HD, Ligtenberg SRM, Fricker HA, Vaughan DG, van den Broeke MR, Padman L. 2012. Antarctic ice-sheet loss driven by basal melting of ice shelves. Nature 484: 502–505.
Rogers AD, Johnston NM, Murphy EJ, Clarke A, eds. 2012. Antarctic Ecosystems: An Extreme Environment in a Changing World. Wiley-Blackwell.
Schiapirelli S, Hopcroft RR. 2011. The census of Antarctic marine life: Diversity and change in Southern Ocean ecosystems. Deep Sea Research II 58: 1–4.
Somero GN. 2010. The physiology of climate change: How potentials for acclimatization and genetic adaptation will determine "winners" and "losers." Journal of Experimental Biology 213: 912–920.
Stokstad E. 2007. Boom and bust in a polar hot zone. Science 315: 1522–1523.
Tin T, Liggett D, Maher PT, Lamers M, eds. 2014. Antarctic Futures: Human Engagement with the Antarctic Environments. Springer.
Turner J, et al. 2013. Antarctic climate change and the environment: An update. Polar Record 1–23.
[UNDP] United Nations Development Programme. 2011. Human Development Report 2011: Sustainability and Equity: A Better Future for All. UNDP.
[UNESCO] United Nations Education, Scientific and Cultural Organization. 2012. UNESCO Institute for Statistics. UNESCO. (16 April 2014; *www.uis.unesco.org/Pages/default.aspx*).
Vaughan DG, Doake CSM. 1996. Recent atmospheric warming and retreat of ice shelves on the Antarctic Peninsula. Nature 379: 328–331.
Vaughan DG, Marshall GJ, Connolley WM, Parkinson C, Mulvaney R, Hodgson DA, King JC, Pudsey CJ, Turner J. 2003. Recent rapid regional climate warming on the Antarctic Peninsula. Climate Change 60: 243–274.
Wall DH. 2005. Biodiversity and ecosystem functioning in terrestrial habitats of Antarctica. Antarctic Science 17: 523–531.
Wall DH, Lyons WB, Chown SL, Convey P, Howard-Williams C, Quesada A, Vincent WF. 2011. Long-term ecosystem networks to record change: An international imperative. Antarctic Science 23: 209.
World Bank. 2014. Explore, Create, Share: Development Data. World Bank. (16 April 2014; *http://databank.worldbank.org/data/home.aspx*)

Ian S. Acuña-Rodríguez is a PhD student at the University of La Serena and the Center for Advanced Research in Arid Zones (CEAZA), in Coquimbo, Chile. Fernando Carrasco-Urra is a PhD student at the University of Concepción, in Concepción, Chile. Cristian Salgado-Luarte is a biologist and a postdoctoral fellow, Rodrigo S. Rios is an ecologist and postdoctoral fellow, and Ernesto Gianoli is an associate professor in the Department of Biology at the University of La Serena, Chile. Gisela C. Stotz is a PhD student at the University of Alberta, in Edmonton, Canada. Marco A. Molina-Montenegro (marco.molina@ceaza.cl) is a titular researcher at CEAZA and an associate professor in the Faculty of Sciences at the Catholic University of the North, in Coquimbo, Chile.