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Climate change and its effects on urban spaces in Chile: A summary of research carried out in the period 2000-2012

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RESUMEN

Se sistematizaron los efectos asociados al cambio climático sobre los espacios urbanos en Chile entre los años 2000 y 2012. El método se basó en la revisión de artículos científicos en tres bases de datos (Scopus, Web of Knowledge y Scielo) mediante el uso de 32 palabras claves. Los resultados mostraron sólo 14 investigaciones que relacionan el cambio climático en espacios urbanos, la mayoría de las cuales fueron estudios de casos centrados en la capital nacional. Los principales efectos sobre los espacios urbanos se basaron en cuatro aspectos: 1) incremento de temperatura (islas de calor, olas de calor), 2) problemas de salud en la población más vulnerable (complicaciones cardiacas, insolación, enfermedades respiratorias), 3) incremento en la demanda de agua y 4) daños en la infraestructura urbana con el consiguiente riesgo para la población. Ante este fenómeno se requiere: 1) la incorporación efectiva de los posibles impactos del cambio climático en los instrumentos de planificación territorial, 2) incremento de las áreas verdes que permita mitigar los impactos de las olas de calor, 3) limitar la construcción de viviendas o servicios públicos en áreas de riesgo, 4) incentivar el diseño de planes de adaptación haciendo participe a la propia población vulnerable y 5) implementar medidas de conservación del agua. Se concluye que el cambio climático está generando en los espacios urbanos efectos que deben considerarse para el diseño y expansión de las ciudades.

ABSTRACT

We have systematized the effects associated with climate change on urban spaces in Chile reported between 2000 and 2012. The method was based on a review of scientific articles in three databases (Scopus, Web of Knowledge and Scielo) using 32 keywords. Only 14 research papers were found related to climate change in urban spaces, most of which were case studies focused on the capital, Santiago. The main effects on urban spaces were found in four areas: (1) increase in temperature (heat islands, heat waves), (2) health problems in vulnerable populations (cardiac complications, heat stroke, and respiratory diseases), (3) increased demand for water, and (4) damage to the urban infrastructure with resulting risk to the population. In these circumstances the following measures are needed: (1) effective incorporation of the potential impacts of climate change into

territorial planning instruments, (2) increased green areas to mitigate the impact of heat waves, (3) limiting of housing or public services in areas at risk, (4) encouraging the design of adaptation plans by involving the vulnerable population, and (5) implementing water conservation measures. We conclude that climate change is causing effects in urban areas that should be considered in the design and expansion of cities.

Keywords: Urban planning, green infrastructure, vulnerable population, global change.

1. Introduction

Knowledge about global climate change has increased considerably in different environmental disciplines and dimensions; however, it is apparent that it was only from the year 2000 that research work and programs addressing this phenomenon spread more strongly to cities (Wilbanks, 2011). The overall pattern of scientific research shows that after 1990 the number of scientific publications grew significantly, with contributions in more than 2000 journals, the USA being the most productive country. Of the 30 843 articles published between 1992 and 2009, 98% were published in English, 0.62% in French, 0.46% in German, 0.19% in Russian, 0.17% in Spanish, and 0.17% in Chinese. The most important themes were the study of temperature change, and more recently the risk produced by greenhouse gases and the rise in sea level (Li *et al.*, 2011). This volume of articles contrasts with the smaller number of research works carried out in urban spaces world-wide, in Latin America, and particularly in Chile, which suggests that we face a great challenge in planning and organizing these spaces as the urban population continues to grow. The Plan de Acción Nacional de Cambio Climático (National Climate Change Action Plan, PANCC) (CONAMA, 2008) proposes that the country's cities and regions must adapt to meet these changes; indeed, it states that all or most of public investments, especially in territorial infrastructure and equipment, must incorporate the viewpoint of climate change to ensure they will be able to tolerate possible variations in climate which may limit the use and durability of materials used (Cifuentes and Meza, 2008). For this policy to have any effect, however, scientific-technical information at a local scale is required (Barton, 2009). We therefore need to investigate the principal findings of the scientific community on the relation between climate change and its effects on urban spaces in Chile.

The aim of the present bibliometric analysis is to determine the state of scientific knowledge on climate change in urban spaces in Chile. In particular: (1) we systematize knowledge on the effects of climate change through bibliometric analysis of the scientific literature published between 2000 and 2012; and (2) we offer indications for urban planning based on selected scientific articles. In this way we hope to manifest the need for research in this area, and point to research challenges for the future.

1.1 Climate change: A global environmental phenomenon with local consequences

Climate change is one of the principal environmental phenomena of modern society, with global consequences that represent a great political challenge for both developed and developing nations. The principal tasks consist in mitigating those human actions that contribute to this phenomenon, and promoting adaptation to changes which go further than the climate (*e.g.*, social, economic, and political areas).

Despite the existence of research on climate change since 1896, when the Swedish scientist Arrhenius stated that burning fossil fuels might cause or accelerate warming of the Earth, it was only in 1988 that the theory of the greenhouse effect was recognized, and the Intergovernmental Panel on Climate Change (IPCC) was established (Maslin, 2004).

Although the existence of this phenomenon is not questioned, its origin is. Discussion centers on whether climate change is of human origin, or is due to natural transformation cycles that affect the Earth. In the context of this debate, it is argued that the effects of the phenomenon are due to an increase in the quantity of greenhouse gases, of natural and/or anthropic origin, which cause a "greenhouse effect" and warm the atmosphere. Despite the dual origin of these gases, in the view of the IPCC (2007) the phenomenon is due principally to gases of anthropic origin, especially the increased volumes of carbon dioxide (CO_2), emitted principally by the combustion of fossil fuels. This international organization considers that the connection established between intensive human activities using coal and petroleum since the

pre-industrial era, and the increase in temperatures that leads to climate change, is highly trustworthy (IPCC, 2007). However, a degree of uncertainty still exists about what will happen in the future, basically as to how the atmosphere will respond to this warming process, and what impacts it will provoke (Moya *et al.*, 2005).

Recent reports indicate that the impacts of global warming are tending towards the most severe scenario proposed by the IPCC (2007), *i.e.* an increase of 5 °C in the temperature and a rise in sea level of up to one metre by the end of the present century (2100). The consequences of this would be a reduction in the supply of drinking water, increase in heat waves, increase in torrential rainstorms, and more frequent and longer periods of drought. It is also proposed that an increase of only 2.4 °C could cause the desertification of the Great Plains of North America, the disappearance of the glaciers in the Andes, extensive fires in tropical forests (leading to a fresh injection of CO_2 into the atmosphere), the elimination of coral barrier reefs and the extinction of one third of all the species on the planet (IPCC, 2007). From this viewpoint, with a potential rise of 3.5 °C, the world's physical, biological and social systems would be unable to adapt to climate change (Ott, 2007; Colwell *et al.,* 2008).

Many of the consequences of climate change can already be observed today on a global level, including most notably hotter days and nights, increased heat waves in many parts of the world, increased frequency of torrential rain, increase in droughts all over the world and a rise in the sea level in some parts of the planet. The impacts generated as a result of these climatological events are expected to have a significant effect on society, the economy and the environment (ONU-HABITAT, 2011).

Although it is possible that population will be able to adapt spontaneously to the processes of climate change, such as the rise in temperature, a significant percentage will be vulnerable to these phenomena (McMichael *et al.,* 2008). Research indicates that the groups most vulnerable to high temperatures are the elderly. This is a cause for concern in countries with ageing populations, such as Chile, where the population projections of the Instituto Nacional de Estadísticas (National Statistics Institute, INE [2002]) indicate that 15% of the population will be aged 65 or over by 2020. It is therefore necessary to draw up public policies which consider, for example, appropriate planning in cities and other high population density areas, to ensure that dimensions such as urban design, housing, transport, etc., will enable the effects of climate change to be mitigated.

Many countries around the world are developing or have created national plans to avoid or mitigate many of the problems associated with climate change. Such plans are well advanced in countries in the European Union, including the UK, as well as Australia, Japan and the USA (Dickinson and Burton, 2011). In Latin America the most advanced country in this respect is Mexico, where the legislature recently passed the Ley General de Cambio Climático (General Law on Climate Change), which establishes a reduction of 30% in carbon dioxide emissions by 2020, and 50% by 2050. The country also expects to produce 35% of its electricity from renewable resources by 2024 (LGCC, 2012).

Chile ratified the United Nations Framework on Climate Change in 1994 and became part of the Kyoto Protocol, thus the country shared the global concern generated world-wide on the subject of climate change. In this regard, several studies have been carried out by technical and governmental organisations, including the PANCC (CONAMA, 2008); the Estudio de la Variabilidad Climática en Chile para el Siglo XXI (Study on Climate Change in Chile in the 21st Century [CONAMA, 2006]); and *La Economía del Cambio Climático en Chile* (The economy of climate change in Chile [CEPAL, 2009]). The PANCC describes the consequences of climate change and explains the principal strategies for addressing it (adaptation, mitigation, creation and strengthening of national capacities). The Study on Climate Change in Chile in the 21st Century studies two aspects: an analysis of the climate scenarios observed at the end of the 20th century, and the climate projections for the different regions of Chile in the last 30 years of the 21st century. Among the main conclusions of this study, it is suggested that there will be a general reduction in precipitation in the country by up to 40%, a temperature rise in all regions, and major impacts on water resources that may affect the country's hydroelectricity generation capacity. CEPAL (2009) makes an economic assessment of the potential effects of climate change on the forestry and farming, hydroelectric and drinking water sectors, which is useful for understanding their relative vulnerabilities. It thus provides vital

information for designing adaptation programmes according to the needs of each region and production sector. The report's conclusions indicate that the effect on the forestry and farming sector will be positive or negative, depending on the region and the type of production. It is expected, for example, that changes in land use will modify and redistribute the country's forestry and farming production, which in turn will transform the demand for labour. In terms of hydroelectricity generation, capacity is expected to fall by up to 20%, which translates into losses of up to US$100 million per year. As for drinking water, it is expected that the decrease in resources will oblige the water companies to incur costs associated with changes in their infrastructure or the purchase of additional water rights to meet demand, which in the long run will result in these costs being transferred to the users.

Many of these problems related to climate change, and the discussion about plans for public policies to deal with them, become more complex when considering the trend of population to become ever more concentrated in cities. Today, urban zones have become the predominant inhabitable space, and this trend is growing ever stronger. From this point of view, the consequences of climate change in urban spaces must be considered, since high population density may further aggravate the effects of this environmental phenomenon.

1.2 Effects of climate change in urban zones and how to respond

The effects of climate change in urban spaces may be summarised as follows: increase in energy demand for cooling in public and private buildings (Kolokotroni *et al.,* 2012); greater impact on the health of the elderly, children and the poor (McMichael, 2000); water scarcity for settlements, industry and society, possibly resulting in lower hydroelectricity generation potential (Carmin *et al.,* 2010); possible population migrations and relocation of infrastructure, etc. (Wilbanks, 2011).

These dangers are concentrated in a series of areas, among which the location of cities must be taken into consideration. For example, it is expected that human settlements and infrastructure located on coasts will be exposed to greater risks due to erosion and rising sea levels as a result of climate change, which will increase as a result of the pressure exercised by human presence (IPCC, 2007). The infrastructure that may be affected includes sea-walls and esplanades, as well fresh water reserves available in coastal wetlands and aquifers due to the intrusion of salt water (Duhart, 2006).

Anticipating the future sea level in a specific area thus adds to the complexity of projecting the location of certain infrastructures, if one thinks, for example, "today's flood is tomorrow's high tide." This makes sense when it is established that current flooding will be more frequent and long-lasting in the future, with consequences for coastal cities which will become inaccessible for much of the year (NOAA, 2012), instead of the occasional flooding that they suffer today. A good example of the effect of climate change on coastal settlements is the village of Newtok, Alaska, which is now facing the need to relocate due to erosion of the coastline. This extreme measure is needed to prevent the population, which has lived on the site for over 2000 years, from being flooded out because the ice is melting (Feifel and Gregg, 2010).

In Mexico, a country which has made notable progress in climate change legislation, the Ley General de Cambio Climático establishes, among the most important measures for regulating urban planning, that by 2015 the country's most vulnerable municipalities must draw up an urban development programme considering the effects of climate change (LGCC, 2012). In Chile, the PANCC 2008-2012 (CONAMA, 2008) states that urban planners must consider climate change impact studies when drawing up municipal regulatory plans, to avoid urban expansion in risk areas. This is expected to result in concrete actions with respect to funding during 2012. The PANCC also states that by 2012 all or most public investment in infrastructure in urban and coastal zones must incorporate studies on the impact of climate change, with particular reference to flooding. The importance of incorporating this focus into urban planning is based on the fact that the risks are increased by inadequate land use planning, as occurs in urban expansion and development in zones with natural dangers, bad management and destruction of nature conservation areas, and population settlements adjacent to wetlands and the coast (Dodman, 2009; Peña-Cortés *et al.*, 2011; ONU-HABITAT, 2011).

The PANCC establishes a series of measures for adaptation to climate change in areas of Chile earmarked as priority development zones, where scien-

tific and technical information is required to enable political and administrative decisions to be taken. On the subject of these measures we should mention the importance of concentrating on urban and coastal infrastructure, considering expansion of infrastructure and defense programmes to protect the population in coastal and riverbank sectors. Furthermore, the capacity for prediction and response associated with destructive flash floods from natural causes should be improved in response to hydrological changes, and variations in hydrology should be considered in the design of bridges and waterworks infrastructure. Extreme climatic phenomena are expected to occur with greater frequency due to climate change, and may produce damage in urban zones and in major infrastructure: roads, bridges, ports, industrial zones and buildings. One of the measures established in the PANCC is the incorporation of results of the available studies on impacts of climate change into territorial planning instruments such as municipal regulatory plans (CONAMA, 2008).

Thus, in the light of the above, it is to be expected that cities will gradually incorporate climate change into their planning processes. Cities in the 21st century will have to modify their planning policies considerably to become ecologically sustainable, with plenty of urban vegetation, gardens and horticulture, and with urban community transport and services that are on a human scale and respect the environment (McMichael, 2000). However, it must not be forgotten that the impacts of climate change on cities will vary depending on their location and on variations in temperature and precipitations, since there will be some geographical areas which will experience a rise or fall in temperature, and others which will be drier or wetter. All cities will be affected by this process (Matthews, 2011).

1.3 Adaptation and mitigation measures to meet climate change in cities

Many cities world-wide are already applying public policies in urban zones to enable their adaptation to the increasing negative consequences of this environmental phenomenon, and for mitigating or moderating the effects of climate change in cities which already have specific design and planning. Adaptation is understood to mean the concrete measures adopted to reduce the negative effects of climate change (IPCC, 2007). International organisations stress the importance of urban planning in managing climate change, since well planned cities will offer greater resilience to climate change than cities which do not incorporate it into planning (ONU-HABITAT, 2011).

Policies for adaptation to climate change in urban zones suggest a series of measures tending to mitigate the adverse effects of climate change on settlements and infrastructure. Territorial planning contributes key elements for improving the capacity of urban systems, by establishing standards for both infrastructure design and installation (IPCC, 2007; Duarte *et al.,* 2006). Based on the above, human settlements, and especially cities, must adapt to climate change in two ways. Firstly by generating more efficient and ecological constructions which help to reduce the causes of climate change, such as greenhouse gases, and secondly by adapting to the growing consequences and risks of climate change (Costello *et al.,* 2009).

In terms of territorial planning policies for adaptation linked to the promotion of particular infrastructure and design standards, the construction of houses with reduced water and electricity consumption should be mentioned. An example of this is Mexico, where the state, through its "green mortgages" programme, subsidises new houses, extensions or repairs for low income families who make use of eco-technologies, such as solar energy, which contribute to the efficient use of natural resources and allow water, gas and electricity consumption to be reduced by more than 40% (ONU-HABITAT, 2012). Another notable example of a country that is focusing on adaptation to climate change is Australia. The measures identified include revising, re-drafting and enforcing construction codes which take changing climatic conditions into account, and managing urban growth in climate-sensitive areas by zoning and regulation (Norman, 2010).

Turning to climate change mitigation measures, there are examples of measures adopted in urban environments which can help to moderate the effects of both heat waves and the torrential rains which cause rainwater drainage systems to collapse; both phenomena are expected to become more intense and recurrent in much of the world (IPCC 2007). The measures include the incorporation of green infrastructure, *e.g.* porous surfaces. This method replaces solid surfaces, like concrete, with soft, permeable

ones like grass, which absorbs the water and helps to reduce the volume entering the drainage system during periods of rain. It also reduces the effects of heat islands through heat absorption, helping to cool the atmosphere, making this a positive feature for incorporation into open air car parks, streets and squares (Matthews, 2011). In large cities such as Manchester, it is recognized that the incorporation of green infrastructure is the principal tool for combating heat islands (EEA, 2012).

The European Union has adopted a number of measures to halt the adverse effects of climate change, including increasing the water and energy efficiency of buildings, reducing water leaks in drains networks, and carrying out scientific research on how to reduce desertification (EEA, 2012). In Singapore, measures have been adopted for re-cycling wastewater on a large scale, using it for industrial and commercial purposes, and, if highly purified, for human consumption (Shaw *et al.,* 2007). Estimates by IPCC indicate that energy demand in cities will reduce for heating and increase for cooling (IPCC, 2007). Examples of this may be seen in Canada: the city of Toronto offers its inhabitants public "cooling centres", installed in community and civic centres, where the most vulnerable population can attend to avoid health damage (Richardson, 2010).

2. Material and methods

This work consists of three methodological and analytic processes: bibliometric analysis, content analysis, and incorporation of indications for territorial planning. A search was carried out in the Scopus (http://www.scopus.com), Web of Knowledge (http://apps.isiknowledge.com) and Scielo (http://www.scielo.org) databases for scientific publications, which included studies relating to climate change in Chile between 2000 and 2012. The search criterion was that articles should be linked to one of the following eight basic keywords: "cambio climático", "cambio ambiental", calentamiento global, "climate change", "climatic change", "environment change", "global change" and "global warming". These basic keywords were combined with words like "city" or "planning", and all the searches included the word "Chile". The final group amounted to 32 compound keywords in Spanish and English, singular and plural (a similar approach may be seen in Pincheira-Ulbrich, 2011) (Table I). The choice of these two languages was justified by the high concentration of

Table I. List of keywords relating to climate change in urban spaces in Chile used in three databases: Scopus, Web of Knowledge and Scielo.

Keywords in Spanish	Keywords in English
1. "cambio climático" ciudad Chile	1. "climate change" city Chile
2. "cambio climático" ciudades Chile	2. "climate change" cities Chile
3. "cambio climático" urbanismo Chile	3. "climate change" town planning Chile
4. "cambio climático" planificación urbana Chile	4. "climate change" urban planning Chile
5. "cambio ambiental" ciudad Chile	5. "climatic change" city Chile
6. "cambio ambiental" ciudades Chile	6. "climatic change" cities Chile
7. "cambio ambiental" urbanismo Chile	7. "climatic change" town planning Chile
8. "cambio ambiental" planificación urbana Chile	8. "climatic change" urban planning Chile
9. "calentamiento global" ciudad Chile	9. "environment change" city Chile
10. "calentamiento global" ciudades Chile	10. "environment change" cities Chile
11. "calentamiento global" urbanismo Chile	11. "environment change" town planning Chile
12. "calentamiento global" planificación urbana Chile	12. "environment change" urban planning Chile
	13. "global change" city Chile
	14. "global change" cities Chile
	15. "global change" town planning Chile
	16. "global change" urban planning Chile
	17. "global warming" city Chile
	18. "global warming" cities Chile
	19. "global warming" town planning Chile
	20. "global warming" urban planning Chile

Note: Compound words shown in inverted commas.

publications on the subject in English, and the high probability of finding publications in Spanish on the country analyzed.

We subsequently analyzed the contents of the articles based on the following dimensions: type of research, geographical study area, research object, methods used and main results. Finally, based on the literature review and the additional selection of some scientific and technical publications chosen for their relevance and recent publication date, general indications for urban planning were drawn up (Table II).

3. Results

The result of the search was a total of 23 scientific articles selected in the first instance, nine of which were discarded from the final content analysis, since they did not contribute directly to the study subject (Guhl *et al.,* 2000; Jorquera *et al.,* 2000; Schuller *et al.,* 2004; Sommerhoff *et al.,* 2004; Salinas *et al.,* 2006; Celis *et al.,* 2007; Borsdorf and Hidalgo, 2008; Ghobakhlou and Sallis, 2008; Ortiz-Royero and Rosales, 2012). Fourteen articles were finally selected from the search, which provided information on climate change and urban planning in Chile in the last 12 years (2000-2012); the majority of these were published after 2008 (Table III).

Ten works were case studies and four were reviews, one of which analyzed the phenomenon of climate change directly (Barton, 2009). The results show that due to the nature of the research problem, the subject ceases to be a national issue and the impacts of climate change on various Latin American cities are studied. The studies concentrated on Santiago (Chile), Sao Paulo (Brazil) and Mexico City (Mexico), and also include the city of Valdivia (Table III).

Among the study objectives, we find greater interest in phenomena related to heat waves and urban heat islands, and their effects on the population. Both phenomena would increase death and disease in advanced age groups and those who are confined and sick in cities with little ventilation (Bell *et al.,* 2008; McMichael, 2000). The research reviewed presents evidence of the vulnerability of population to extreme climatic events, whether involving high or low temperatures, and exhibits a resulting increase in mortality (McMichael *et al.,* 2008), as well as health problems —respiratory, cardiac and sunstroke— among the most vulnerable population (children and the elderly) (Bell *et al.* 2008).

The methods used in the research were principally quantitative, together with medium and long term projections for certain variables in the face of climate change. In particular, the following are analyzed: behaviour of water run-off in drought periods (Müller and Reinstorf, 2011); the current state and expected evolution of mountain glaciers (Bodin *et al.,* 2010); the effects of high temperatures on the population (Bell *et al.,* 2008); the consequences of the reduction in respirable particulate matter associated with the mitigation of greenhouse gases (Cifuentes *et al.,* 2001; Bell *et al.,* 2006; Grass and Cane, 2008); an assessment of the effect produced by cities on the atmosphere (Molina and Molina, 2004); and the incorporation of the risk focus in megacities (Kopfmüller, 2009).

Another important factor is changing land use, which could seriously affect the availability of drinking water for city populations, with the consequent health risks (Núñez *et al.,* 2006; Bodin *et al.*, 2010). It is also found that these modifications in land use patterns could affect urban infrastructure, as a result of possible flooding (Montenegro-Romero and Peña-Cortés, 2010; Müller and Reinstorf, 2011).

In the light of these results, certain indications are suggested to help urban centers to adapt to climate change on the basis of territorial planning instruments.

Table II. Selection of manuscripts as the basis for planning indications.

Type of bibliographic source	Publication
Criteria and Chilean standards	Conama (2006, 2008), MMA (2011).
Standards and International Studies	Dourojeanni and Jouravlev (1999), IPCC (2007), Hunt and Watkiss (2007), PNUD (2007), Ulloa *et al.* (2008), FFL (2008), Carrington *et al.* (2010), Feifel (2010), Convención Alpina (2011), ONU-HABITAT (2011, 2012).
Books and scientific papers	Moya *et al.* (2005), Schmidt and Lébre (2007), Grimmond, (2007), Mathey *et al.* (2010), Baumgardner *et al.* (2012).

Table III. Summary of research works on global climate change and indications for urban planning.

Authors and type of research	Geographical area of study	Study objective	Methods used	Principal results	Indications for urban planning
Barton (2009). Bibliographical review (case study)	Santiago (Chile)	Incorporate climate change considerations into strategic planning of cities and regions.	Review of international plans and experiences. Review of technical documents issued by IPCC.[1]	Climate change adaptation processes must be integrated into existing decision-making structures, as well as territorial planning, resource management, risk management, etc. To reduce the vulnerability[2] of population to climate change the following must be considered: a) the impact is greater on the most economically vulnerable population; b) adaptation measures are found most frequently in higher income social groups; c) the time horizons are limited (short-term policies), making suitable adaptation measures difficult; d) people are confident that the international community will intervene in the event of natural disasters caused by climate change, leading to lack of local investment for events considered improbable.	Incorporate considerations of urban design in the face of climate change into standards and regulations for urban spaces. This requires a land use policy (housing density, limitations in high risk zones), which will include, for example, new building regulations (drainage networks that will withstand drastic increases in precipitations), insurance against disasters (such as flooding), etc. (IPCC, 2007). It must be ensured that the most vulnerable populations can participate actively in the development of their own action plans, with the support of local authorities and assistance agencies; this will help to reduce the risks of events related with climate change (ONU-HABITAT, 2011). It is suggested that in view of the scarcity of research into adaptation of cities to climate change, case studies in other cities with similar locations and vulnerabilities should be considered, and transfer of the results studied (Hunt and Watkiss, 2007).
Bell *et al.* (2006). Case study	Santiago (Chile), São Paulo (Brazil), Mexico City (Mexico)	Investigate the health consequences of changes in the use of fossil fuels, in two scenarios, one maintaining current emissions and the other regulated according to emission control policies associated with climate change policy in the period 2000-2020.	Analysis of current emissions of air pollutants. Estimate the decrease in emissions of particulate matter by 10% annually. Health statistics (hospital admissions).	It is estimated that in the three cities, 60 000 hospitalizations due to respirable diseases, over 300 000 visits by children and more than 700 000 visits for respiratory emergencies could be prevented. Savings of up to $165 billion dollars by 2020 are estimated for the three cities.	Generate local initiatives to reduce greenhouse gases; among the measures that can be implemented is the replacement of energy-inefficient plants, promotion of renewable energy (*e.g.*, Torres and Peña-Cortés, 2010), updating and implementation of energy efficiency standards in buildings, increasing energy awareness and public education, and creating groups specialized in climate change that promote these practices in cities (CONAMA, 2008; Feifel, 2010).

Table III. Summary of research works on global climate change and indications for urban planning.

Authors and type of research	Geographical area of study	Study objective	Methods used	Principal results	Indications for urban planning
Bell *et al.* (2008). Case study	Cities of Mexico (Mexico), Sao Paulo (Brazil), and Santiago (Chile)	Analyze the relationship between socioeconomic factors that determine the vulnerability of population to high temperatures.	Logistic regression analysis of 754 291 deaths between 1998 and 2002 and their relation with the variables of temperature, gender, age and level of education.	No significant differences were found between genders in the number of deaths associated with high temperatures. The probability of death due to high temperatures increases in those aged over 65 (average 4.4%) in all three cities. Except for Sao Paulo, no differences between levels of education were found for vulnerability to heat.	Other effects that climate change may have on females must be assessed, principally related to sociocultural aspects and role distribution, for example discrimination and access to water, and heavier burden of agricultural work (Ulloa *et al.*, 2008). Awareness of the elderly age-group needs to be heightened in planning for urban spaces and public transport, *e.g.*, high reflectivity paint to reduce the temperature inside buses and other means of public transport (Grimmond, 2007), to mitigate the risks to this population due to possible drastic temperature increases. Assistance to urban residents, especially "vulnerable" persons, in adapting their behaviour and lifestyles to high temperatures (ONU-HABITAT, 2011). Map the areas most vulnerable to heat waves and establish mitigation measures. Changes in urban infrastructure and territorial regulation, increasing the amount of urban green areas (ONU-HABITAT, 2012). More studies are required to relate educational level with vulnerability to heat in medium-sized cities.
Bodin *et al.* (2010). Case study	Laguna Negra Basin, Santiago (Chile)	Describe the evolution and current state of the glaciological and geomorphological cryosphere in the basin, in order to assess its hydrological importance, since it is the main drinking water source for the city of Santiago during the summer period.	Geomorphic field mapping, multi-temporal analysis of orthophotos, temperature records.	Reveals a decrease of 44.7% of the glacier between 1955 and 1996. There is an estimated loss of at least 3.8 million m^3 of glacier ice per decade in the basin under study.	Promoting actions to protect these geographical areas including knowledge transfer and protection conventions, based on international agreements such as the Alpine Convention (Alpine Convention, 2011; MMA, 2011). Since it is not possible to stop the effects of climate change on glaciers, processes should promote adaptation measures such as the efficient management of water resources (CONAMA, 2006, 2008; MMA, 2011).

Table III. Summary of research works on global climate change and indications for urban planning.

Authors and type of research	Geographical area of study	Study objective	Methods used	Principal results	Indications for urban planning
Cifuentes *et al.* (2001). Case study	Mexico City (Mexico), Santiago (Chile), São Paulo (Brazil), New York (U.S.)	Evaluate the consequences of the decrease of respirable particulate matter (PM10) on people's health (as a factor related to the reduction of greenhouse gases emissions).	Analysis of official statistics for respiratory diseases. Projection scenario for reducing greenhouse gases (2000-2020).	Mitigation of 10% of the particulate matter associated with climate change policies could reduce premature deaths associated with air pollution by 64 000.	The authorities have a responsibility to deal with those activities that produce greenhouse gases emissions at the local level. Encouraging the reduction of particulate matter not only improves general welfare, but public finances also improve due to savings in health treatments (ONU-HABITAT, 2011).
Ebert *et al.* (2010). Case study	Santiago (Chile)	Check whether the occurrence of floods or landslides is the result of natural and anthropogenic interactions and whether these risks are distributed according to socioeconomic factors.	Analysis of land use and land cover changes between the years 1992 and 2002, through remote sensing.	Tests the hypothesis that phenomena such as floods and landslides are the result of natural and anthropogenic interactions. Does not confirm the hypothesis that lower income populations are at increased risk of suffering the consequences of catastrophic events over wealthier households.	Incorporate risk management plans in urban areas most likely to be affected by floods and landslides. Among the measures to be incorporated into risk management is investing in mitigation projects, such as physical structures to contain landslides that could jeopardize urban spaces (Carrington *et al.*, 2010). In risk areas, encouraging the creation of parks, "buffer" zones, urban and peri-urban forestry (Dourojeanni and Jouravlev, 1999). More research is needed on the relationship between income and risk because other research suggests a close relationship between the two (PNUD 2007; IPCC, 2007; Romero *et al.*, 2010).
Grass and Cane (2008). Case study	Santiago (Chile)	Identify the weather and air pollution associated with high mortality. Evaluate the relative importance of weather and pollution concentrations in periods of high mortality.	Air pollution statistics and death statistics, data analysis using principal components.	Air pollution increases the causes of death produced by weather conditions (winter temperature decrease).	Encourage public and private companies to reduce greenhouse gases in order to obtain benefits in relation to technology transfer, access to financing, etc., through the Clean Development Mechanism established in the Kyoto Protocol, by which developed countries sign agreements with developing countries to acquire CERs, allowing industrialized countries to meet their emissions reduction targets (also called "carbon market") (Schmidt and Lébre, 2007; CONAMA, 2008).

Table III. Summary of research works on global climate change and indications for urban planning.

Authors and type of research	Geographical area of study	Study objective	Methods used	Principal results	Indications for urban planning
Junk (2012). Literature review	South America	Summarize the current state of knowledge on wetlands extent, distribution, vulnerabilities and security considering climate change scenarios.	Review of statistics provided by a specialized research center, review of wetlands protection policy.	Wetlands cover about 20% of South American territory; it is expected that a rise in temperatures will have a strong effect on the wetlands and the species that live there.	Studies are needed to quantify the benefit of wetlands and calculate the economic value they provide to their inhabitants, in order to facilitate discussion of their protection with political and interest groups. Wetlands provide a number of benefits to urban environments, such as serving as natural protections against floodings; offering the first line of defense against the action of hurricanes and severe storms; reducing the impact of high winds; storing up to 40% of the carbon produced by the planet; buffering the discharge of connected rivers from any heavy rains and providing drinking water to the population (Moya *et al.*, 2005).
Kopfmüller *et al.* (2009). Literature review, case study	Santiago (Chile)	Incorporate the risk habitat megacity approach, which aims to assess the current risks in priority areas such as housing, drinking water, storm water drainage etc., and propose development paths.	Review of indicators of economic development, air quality, and land use management.	A decrease of up to 50% in the availability of potable water is expected by 2040, which could bring significant conflicts between different water-consuming sectors: agriculture, industry, and private households.	The protection of both underground and surface catchment should be promoted, avoiding activities that cause degradation or prevent the restoration of the ecosystem (Dourojeanni and Jouravlev, 1999).
McMichael *et al.* (2008). Case study	Delhi (India); Monterrey, Mexico City (Mexico); Chiang Mai, Bangkok (Thailand); San Salvador (El Salvador); São Paulo (Brazil); Santiago (Chile); Cape Town (South Africa); Ljubljana (Slovenia); Bucharest (Romania); and Sophia (Bulgaria)	Establish the vulnerability of urban populations to climatic events such as high and low temperatures in low and middle income cities in non-OECD member countries.[3]	Monitoring daily average temperatures using the autoregressive Poisson model (two- to five-year series) considering the seasons, relative humidity, air pollution, day of the week and holidays.	Mortality rates increase with colder temperatures in all cities except Ljubljana, San Salvador and New Delhi; the same happened when the heat rose in all cities except Chiang Mai and Cape Town.	Study the integration of "green infrastructure" in urban planning (Mathey *et al.*, 2010; ONU-Habitat, 2011), incorporating vegetation to mitigate heat waves in urban areas by increasing circulation and humidity. Consider heat waves as a public health problem, thereby generating policy programs intended to prevent the consequences of these phenomena in the vulnerable population (ONU-HABITAT, 2012).

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Authors and type of research	Geographical area of study	Study objective	Methods used	Principal results	Indications for urban planning
Molina and Molina (2004). Literature review (case study)	Los Angeles, (U.S.), Mexico City (Mexico), Toronto (Canada), Delhi (India), Beijing (China), Santiago (Chile), São Paulo (Brazil), Bogotá (Colombia) and Cairo (Egypt)	Evaluate the effect of large urban areas on the Earth's atmosphere.	Review of research related to pollution and air quality of the cities studied.	Air pollution caused by industry, transport and heating has serious public health consequences and has the potential to contribute significantly to climate change.	Cities should increase the energy efficiency of urban structures, and have a land use plan that limits urban sprawl so as to reduce the need to travel. It should also increase adaptability by incorporating risk management measures in city planning instruments, investment in infrastructure, and clear policies for planning and construction (ONU-HABITAT, 2011).
Müller and Reinstorf (2011). Case study	Santiago (Chile)	Identify potential land use and land cover in a river basin (San Ramón River) with regard to its run-off behaviour and its effects on the adjacent urban area (eastern Santiago).	Hydrological modelling (HEC-HMS). Analysis of climate change predictions. Interviews with specialists. Analysis of zoning laws.	The changing pattern of land use in the river basin (either anthropogenic or due to climate change) after prolonged periods of drought produces higher flood risks that may affect adjacent urban areas.	Integrate periurban areas into territorial planning processes, as these spaces influence the run-off regime of rivers flowing into human settlements. Among the measures that can be implemented is the incorporation of vegetation and reforestation, not only to mitigate storm water run-off but also to mitigate heat island effects (Baumgardner *et al.*, 2012). Developing land use planning; incorporating an ecological approach to human settlements and to the definition of land use (FFL, 2008).
Núñez *et al.* (2006). Case study	Valdivia (Chile)	Determine the economic value of the temperate forests of Chile in maintaining the production of drinking water for human consumption.	Economic valuation using the production function approach.	The decrease in water supply resulting from the conversion of native forests to other land uses can have serious negative effects on the availability of potable water.The estimated value per cubic meter of water produced by temperate forest is US$0.066 in the summer and US$0.025 during the rest of year.[4]	The conservation of peri-urban and protected areas or areas covered by native forest becomes relevant to the notably decreased rainfall in southern Chile in recent decades (CONAMA, 2006), and to the climate change scenario; the protection of river basins is crucial for the supply of drinking water, vital for urban development. Generate water efficiency plans and reduce losses in the water distribution system in urban areas (leaks, irrigation methods, maintenance). According to ONU-HABITAT (2011), water strategy should consist in: losing less, using less, demanding more and developing new resources.

Table III. Summary of research works on global climate change and indications for urban planning.

Authors and type of research	Geographical area of study	Study objective	Methods used	Principal results	Indications for urban planning
Romero *et al.* (2010). Case study	Santiago (Chile)	Establish the relationship between thermal areas and the socioeconomic conditions of the population.	Monitoring temperatures in downtown Santiago municipalities (Cerrillos and Peñalolén). Analysis of socio-economic statistics, including education of the head of the household and the possession of a set of goods, classification proposed by Adimark (2004)	Spaces inhabited by lower-middle and low socioeconomic groups tend to concentrate higher temperatures and poor land cover (less vegetation). The upper and middle socioeconomic groups have higher land cover and lower temperatures.	Planning instruments such as PLADECOS, regulatory plans, etc., should take into consideration the maintenance and creation of green areas. This reduces the vulnerability of the population to climate change, particularly in low-income socio-economic groups.

[1]IPCC: Intergovernmental Panel on Climate Change.
[2]Vulnerability is defined as the degree of susceptibility or inability of a system to address the adverse effects of climate change and, in particular, the variability of weather and extreme events. Vulnerability is a function of the character, magnitude and rate of climate change to which a system is exposed, and its sensitivity and adaptive capacity (IPCC, 2007).
[3]OECD: Organization for Economic Cooperation and Development. Per capita income of the cities under study range between $440 and $9,780 annually, compared with $21,410 in developed countries like England (1998 figures).
[4]To express the results in dollars, the average exchange rate reported by the Central Bank of Chile(2004) for the study period, equal to $615 Chilean pesos per dollar, was used.

The measures identified include: (1) effectively incorporating the possible impacts of climate change into municipal regulatory and development plans (Planes de Desarrollo Comunal, PLADECOS), and in general into territorial planning instruments; (2) increasing green areas to mitigate the impacts of heat waves; (3) limiting construction of housing or public services in risk sectors (*e.g.*, potential flood zones); (4) encouraging the design of adaptation plans that include vulnerable population; and (5) implementing water conservation measures, for example by protecting native forests in basins and reducing the losses in water distribution system (leaks, irrigation methods, maintenance) (Table III).

4. Discussion

Research on climate change has developed rapidly during the 20th and 21st centuries; bibliometric analyses show the production of just one work in 1907, rising to 862 articles in 2009. Of these, 98% are written in English (Li *et al.,* 2011).

In Chile, the concern of scientists over climate change in urban environments has received little attention. Almost all of the articles reviewed were published after 2008. Recent studies show that, worldwide, the majority of studies come from the area of natural sciences, hence the interest in the physical and biological aspects of the phenomenon. In this framework, research on urban spaces has advanced less (Böll, 2010; Li *et al.,* 2011). For this reason, and considering that cities are the principal habitats of humanity as well as the centers of economic and political activity, it is striking that scientific projects and research work in the area of climate change have not yet recognized their due importance (PANCC [CONAMA, 2008]; Estudio de la Variabilidad Climática en Chile para el Siglo XXI [CONAMA/ Departamento de Geofísica de la Universidad de Chile, 2006]; and *La economía del cambio climático en Chile* [CEPAL, 2009]).

International organizations (ONU-HABITAT, 2011) stress the importance of urban planning in managing climate change, since well planned cities will offer greater resilience to climate change than cities which do not incorporate this issue into their planning. Nevertheless, scientific research works in the area of territorial and urban planning are scarce in Chile. Those that exist are centralized on the national capital, while the consequences of climate change in medium-sized or coastal cities are unknown. This situation is similar to that which occurred initially in developed countries, including Canada, where at first attention on climate change concentrated on research into climate models and the development of scenarios, as well as on collaboration between scientists; in this initial stage less importance was given to generating explicit actions for cities to adapt to climate change (Dickinson and Burton, 2011).

The importance of using territorial planning lies in the promotion of certain infrastructures and design standards that help cities mitigate and adapt to the effects of climate change. One of the urban planning measures that can help to achieve these objectives is the construction of dwellings that save on water and electricity consumption. In Mexico for example, the state subsidises new houses, extensions or repairs for low-income families making use of eco-technologies through its "green mortgages" programme (ONU-HABITAT, 2012).

In this context, Chile should give timely consideration to concrete actions in the framework of a consistent public policy, since a large number of the country's urban spaces lie in coastal areas. If we also consider that inhabitants with medium and low income tend to live in environmentally less favoured sectors (Romero *et al.,* 2006; Peña-Cortés *et al.,* 2009), we may conclude that the increasing severity of climate change will pose increased risks for these social groups. The consequences of this phenomenon therefore will not be equally distributed across society, since poorer populations will suffer its effects earlier and more intensely (Stern, 2007).

Among the predicted consequences in urban spaces are reduction in drinking water supplies, increase in heat waves, increase in torrential rainstorms, more frequent and longer periods of drought, and a rise in sea level. Heat waves and urban heat islands are inter-related; heat waves are associated with low wind speeds and high humidity over large geographical areas, exposing the population to high temperatures (ONU-HABITAT, 2011), while heat islands are defined as "excessive heat generated in an urban environment due to human activity" (Capelli de Steffens *et al.,* 2001). Heat islands are associated mainly with downtown areas and are caused by the elimination of plant cover and the introduction of artificial elements like concrete and asphalt. The obstruction of fresh

breeze causes temperatures to remain higher, with differences of 10 °C or more above the surrounding areas (EEA, 2012). This phenomenon is not necessarily limited to large cities; even small towns of 1000 inhabitants may be affected (Li *et al.,* 2004).

The most important phenomena may be drought and high temperatures, given their implications for electricity provision, and for water supplies to ecological and human systems (IPCC, 2007). A reduction in the quantity and quality of drinking water may have a secondary effect on energy for heating and refrigeration, and an increase in the tariffs for both water and electricity, due to reduced water levels in reservoirs. For example, in Europe this might affect the production capacity not only for hydroelectricity, but also nuclear energy due to the need for abundant water to cool the reactors (EEA, 2012).

Chile is considered to be one of the countries with greatest economic and social inequalities in the world (OCDE/CEPAL, 2005; Emmerich, 2011). If we add the fact that most vulnerable social groups occupy the highest risk areas —for example along river banks, where they are exposed to flooding, or areas that suffer frequent and prolonged periods of drought, which in turn have a greater effect on more vulnerable families— it may be concluded that the increasing severity of climate change brings greater risks to these social groups in the country (Stern, 2007).

It would be interesting to investigate or assess whether Chilean indigenous communities possess traditional knowledge that may help them in dealing with climate change, in order to learn about and support this knowledge, as is happening with the Inuit in Canada (Nunavut Government, 2003).

5. Final considerations

Climate change will produce a series of effects on urban environments and their inhabitants. To meet these challenges it is vital to have updated local studies of its potential effects. The present work reports the small number of scientific publications relating to climate change in urban spaces in Chile, and points to the fact that those which exist, are concentrated mainly on the city of Santiago. It is therefore necessary to extend research to other regions and medium-sized cities, so that results can be incorporated into future territorial planning instruments, as occurs in London and New York (Hunt and Watkiss, 2007). It is also necessary to investigate to what extent the PANCC considerations (CONAMA, 2008) are incorporated into municipal regulatory plans.

There is an urgent need for studies to establish physical and social vulnerability in urban spaces, and thus expose which districts (or territories) may be most affected by this process in the medium term, and identify priorities and adaptation measures. For example, an effective measure in cities affected by heat islands in summer due to the scarcity of green areas would be the incorporation of "green roofs" into public infrastructure and other buildings. These roofs are totally or partially covered with vegetation, which retains up to 75% of rainwater and can cool the surrounding space by between 3° and 11°, reducing the need for air conditioning inside the building (Carmin *et al.*, 2010).

Urban planning that seriously considers adaptation to climate change in Chile (or Latin America) requires the adoption of a series of structural (*e.g.*, green infrastructure) and non-structural measures (*e.g.*, education), and even the possibility of relocating human settlements (Norman, 2010). For example, coastal defenses and hydroelectric plants should take into account future rainfall conditions; likewise, bridges must be designed to resist possible drastic increases in precipitations and water flows (Levine and Encinas, 2008). The Confederation Bridge, which joins Prince Edward Island to continental Canada, is considered to be the most cited example of adaptation to climate change in infrastructure, being designed to withstand a rise in sea level of more than one metre (Gregg, 2010). However, these structural measures make no sense to the community if its members are not properly informed. The State must therefore ensure the transfer of knowledge from the political-scientific world by means of education (Lor and Britz, 2007; Monroy-Concha and Pincheira-Ulbrich, 2013). In this way, education can influence policy design, facilitate local governability and improve the organizational control and responsibility of institutions (Duhart, 2006).

Studies carried out in the Biobío and Araucanía regions conclude that the regulatory plans of a large percentage of municipalities are currently out of date, especially in the Araucanía region (Sanhueza and Peña-Cortés, 2010; Gutiérrez and Peña-Cortés, 2011). This brings an opportunity for the incorpora-

tion of a focus on climate change adaptation when the plans are updated, which in turn will help to design more resilient districts with greater capacity to withstand the expected impacts of climate change.

6. Conclusions

This work reports the scarcity of scientific research relating to climate change in urban zones of Chile (and Latin America in general); only 14 publications were recorded during the study period, 70% of which are recent (2008-2012). In geographical terms, 12 were related to Santiago and only one to the city of Valdivia.

The review shows there is greater interest in analyzing subjects related to the vulnerability of population to high temperatures (three works) and determining the causes of floods and landslides (two works). On the other hand, there is a lesser interest in studies associated with the effects of respirable particulate matter, the care and maintenance of peri-urban areas, and the role of temperate forests in contributing to the production of drinking water if precipitations should diminish. Only one study suggests the need to incorporate climate change as an element of city and regional planning.

The indications for urban planning include: (1) effectively incorporatimg the possible impacts of climate change into municipal regulatory plans and municipal development plans, and in general into territorial planning instruments; (2) increasing green areas to mitigate the impacts of heat waves; (3) limiting construction of housing or public services in risk sectors (*e.g.*, potential flood zones); (4) encouraging the design of adaptation plans that involve the vulnerable population; and (5) implementing water conservation measures, for example by protecting native forests in basins and reducing the losses in the water distribution system (leaks, irrigation methods, maintenance). For the above mentioned adaptation measures to be effective, it is necessary to include the vulnerable population in these processes in order to reduce the risks of events related to climate change.

Finally, it is essential to generate scientific research which will provide timely information for its incorporation into plans for the renovation and re-urbanization of settlements, since decisions taken today on these issues will affect the quality of life of populations which inhabit —or will inhabit— these urban spaces. In the medium term, decision-makers will not be able to remain uninvolved in this global process.

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