Article

Climate Change and Health in the Urban Context: The Experience of Barcelona

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Abstract

Climate change poses huge challenges for public health, and cities are at the forefront of this process. The purpose of this paper is to present the issues climate change poses for public health in the city of Barcelona, how they are being addressed, and what are the current major challenges, trying to contribute to the development of a baseline understanding of the status of adaptation in cities from a public health perspective. The major issues related to climate change faced by the city are common to other urban centers in a Mediterranean climate: heat waves, water availability and quality, air quality, and diseases transmitted by vectors, and all are reviewed in detail with empirical data. They are not a potential threat for the future, but have actually challenged the city services and infrastructure over the last years, requiring sustainable responses and rigorous planning.

Keywords

climate change, cities, public health, adaptation, evaluation

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Introduction

Climate change poses huge challenges for public health.[1] Cities are in the forefront of this process.[2] Housing and mobility policies, with a strong influence on the mitigation of climate change, are often a municipal responsibility. Key aspects of strategies to adapt to climate change lie in urban planning, a key aspect of city government. Although the direct responsibility of local governments in the health field varies across jurisdictions, many cities also manage public health services, and even more exert some influence in the health care facilities within their boundaries.

Most publications in the climate and health area focus on the magnitude of the problem. There are fewer documenting current actions in adaptation, as most of those dealing with health and adaptation to climate change discuss this issue in a generic or abstract sense.[3] Our purpose with this paper is to present the issues climate change poses for public health in the city of Barcelona, how they are being addressed, and what are the current major challenges, with a five year perspective. We intend to contribute to the development of a baseline understanding of the status of adaptation in cities from a public health perspective.

Institutional Context

The 1997 Kyoto protocol was a turning point for climate change policy: in 2002 the European Union signed, and Spain ratified it, which meant addressing its share of responsibilities as a member state of the European Union in reducing emissions. The institutional context created by this situation is relevant for the city.

After the ratification of the Kyoto protocol, the government of Spain approved in 2006 its first climate change and clean energy strategy to address its obligations, as well as a National Plan for adaptation to climate change.[4] Over the years, successive National Plans have been approved. As this paper is drafted (in early 2016) the third Plan is in operation.[5] The governments of many Autonomous Communities (similar to the US states in the quasi-federal organization of Spain) have approved their strategies and plans. In Catalonia, the first governmental report on climate change was published in 2005, describing the situation and the policies developed in different sectors, followed by a framework for mitigation covering 2008–2012, and the Catalan strategy for adaptation in 2012. Also, several large cities (including Barcelona) have prepared their own assessments and plans.

In dealing with climate change, the city of Barcelona built on previous experience, and specifically on its efforts linked to the Local Agenda 21 initiative, as well as through international commitments such as the Covenant of Mayors in 2008 and the Mayors Adapt program in 2014. The Covenant of Mayors led to the city "Energy, Climate Change and Air Quality Plan for 2011-2020"

(or PECQ for its Catalan acronym),[6] which aims at reducing per capita greenhouse gas emissions by 23% in 2020 (from the 2008 levels). The plan reinforces the link between climate change and air quality. The Mayors Adapt program has prompted the preparation of a "Resilience and Adaptation to Climate Change Plan," expected by 2016 and for which a preparatory report compiling data has been published.[7] In the recent Paris Conference the Mayor presented Barcelona's "Commitment to the Climate," a road map for the next two years prepared with the participation of over 800 organizations; among its objectives it aims to reduce by 40% the City's green house gas emissions and to increase its urban green space by 1 m^2 per inhabitant by 2030.

Meanwhile, the city has also developed specific plans for topics covered in these major plans (among others air pollution abatement, or the greening of the city), has created a Resilience Office, and has become an active member of international networks such as the C40 network and the International Council for Local Environmental Initiatives (ICLEI), which bring together large cities sharing a commitment in this field.

The Effects of Climate Change in Barcelona

Barcelona lies in the Mediterranean shore, in Catalonia (North East of Spain). Its climate is characterized by warm to hot, dry summers and mild to cool winters. During the summer season, it is dominated by subtropical high pressure cells, making rainfall unlikely except for the occasional thunderstorm. Barcelona is located on the eastern coast of the Iberian Peninsula, so Atlantic west winds often arrive in Barcelona with low humidity, producing no rain. The proximity of the Atlantic, its latitude, and the relief, are the reasons why the summers are not as dry as in many other Mediterranean Basin locations. Barcelona has on average only 55 precipitation days a year; rainy days per month range from 2 in July to 6 in October. The average annual precipitation is less than 640 mm, ranging from 20 mm in July to 91 mm in October. Most years the city has relatively mild winters and very warm summers. In the warmest month – August, typically temperature ranges from 25°C to 31°C during the day and about 20°C at night. In recent years, the highest temperature recorded during the day was 37.4°C (August 2010), and during the August 2003 heat wave, the record average daytime maximum temperature was 32.8°C. The consequences of climate change in such a context will be a more extreme summer, with fewer days of precipitation, more heat, and heat waves both more frequent and more intense.

Such a Mediterranean climate is shared with cities in the Mediterranean Basin, but also in more distant shores such as California, Chile, Southern Australia, or South Africa. Among the cities that have developed detailed plans for adapting to climate change only a few are in a Mediterranean climate context. A review conducted for major cities found relevant reports from San Francisco in California and from Sydney and Melbourne in Australia.[8]

The city of Barcelona is a compact city, with a population of 1.6 million on some 100 km2 (the Collserola hills, a natural park, occupy about 17% of the city territory). Constrained by the Llobregat and Besòs rivers on each side, it is part of a larger Metropolitan Region with a population of 4.5 million. Within the Metropolitan Region are intense flows to and from the city to work or study, part of them without mass transport infrastructure and thus forced to rely on motor vehicles for mobility. The city has evolved in a couple of decades from being an industrial center to a service-based economy, where tourism has become a major component. Its harbor has expanded from its traditional commercial activity to become the largest cruise node in the Mediterranean, and its airport has expanded over the last decades.

For the Spanish Health and Climate Change Observatory, the four main issues posed by climate change for public health in the country are heat waves, water availability and quality, air quality, and diseases transmitted by vectors. How these issues impact in the city of Barcelona is reviewed in detail below.

Heat Waves

The existing heat wave early warning system was established after the major heat wave in the summer of 2003. It is triggered by the prediction of higher temperatures (set at the 98th percentile of temperature). It relies on warning the general population through the media, and also addressing the frail and those at risk through the health and social services.

The warning system is part of the Operational Heat Wave Plan (POCS in its Catalan acronym) managed by the Health Department of Catalonia on a county basis. It relies on the prediction of a heat wave by the weather service (Servei Meteorològic de Catalunya), defined as being above the 98th percentile of the historical temperature records in each county. It also relies in the identification of persons at risk by health and social services, and the issue of advice regarding avoiding extreme heat, using air conditioning, maintaining water balance, and reviewing the use and dosage of some medications. Measures to preserve the operational capacity of health facilities during such an event are also designed. The POCS has been activated over the 2004–2015 warm periods, and a summary report has been produced every year.

Barcelona-based researchers in the Center for Research in Environmental Epidemiology (CREAL) have tried to evaluate whether the warning system had any effect in reducing mortality during heat wave episodes, and compared it to other cities. No changes in mortality during heat waves were seen since 2003, but heat waves were more intense than in the previous years (an average increase of 2°C).[9] Figure 1 shows the association between average temperature and mortality in the years before and after 2003: as can be seen, after 2003 when the system went into operation there were more intense heat waves, and

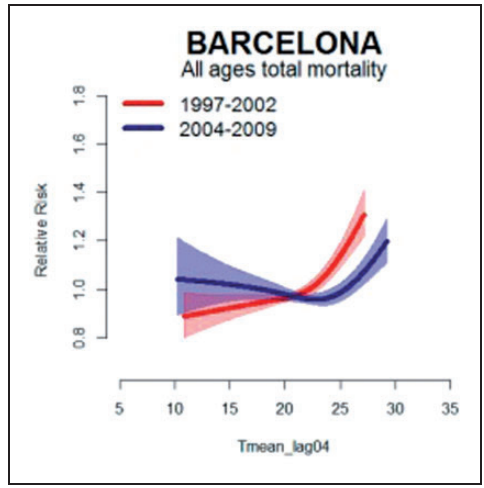

Figure 1. Mean temperature-mortality relationship (with 95% confidence intervals) in the years before 2003 (Period1, red line) and after 2003 (Period 2, blue line) in the city of Barcelona. The x axis shows mean temperature (°C).
Source: de Donato et al., 2015.

mortality did not change, which may be interpreted as suggestive of a potential positive effect. More specific analyses for both respiratory and cardiovascular causes of death were done, and did not show any significant difference.

Water Availability and Quality

Climate change results in fewer days of precipitation, and heavy occasional rains which have caused periodic overflowing of the sewage system and of the sewage treatment capacity in the city. Over the last decades, a system of underground water retention tanks has been developed to deal with this issue, and were capable of storing 600,000 m^3 of rain water by 2014. Plans for further expansion of this system continue. Also, the Llobregat and Besós rivers on both sides of the City may be subject to wide flow variations periodically, and this may threaten key infrastructure located near the mouth of these rivers.

However, the main issue posed in the Mediterranean basin by a change in precipitation patterns refers to water availability and quality. This has been addressed over the last decade, as the city had to confront periodic droughts and a water supply derived from sources that were polluted.

The city of Barcelona derives most of its drinking water from surface water. Traditionally this came from reservoirs in the Llobregat and, since the mid-1960s, also from the Ter. Besides the challenges posed by human pressure in a densely populated area for water quality (which have been met over the years by

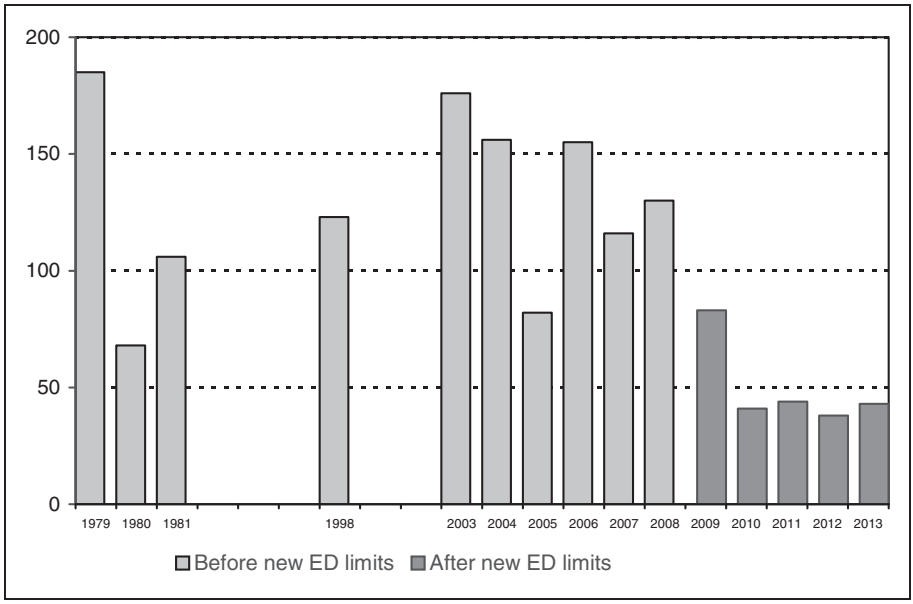

Figure 2. Average THMs concentration in samples of the city drinking water of predominantly Llobregat basin source (B zone). Barcelona, 1979–2013.
Source: 1979-81 results are from research studies by the CSIC, 1998 values are from a study in the Public Health Agency as the laboratory methods for monitoring THMs were being piloted while the European Directive was being transposed into national legislation, and from 2003 on values are the official control values reported by the Public Health Agency.

the development of more effective sewage treatment plants), the Llobregat basin suffers from pollution caused by potash mining. As a result, the drinking water derived from sources related to the Llobregat river had a high saline contents, and reached high trihalomethane (THM) levels, mainly due to brominated compounds. This was documented in the 1970s, but the perceived lack of alternative sources of water and the lack of regulations covering THMs in drinking water in Spain left the issue unresolved.[10]

With the European Directive of 1998 the situation had to change. This regulation mandated that EU member states were obligated to transpose their limits for THMs into national legislation; these were also lowered in 2009. At the same time, the fact that drinking water in the city often reached levels that were unsatisfactory spread from the professional and scientific milieu into the media, and public opinion activated political pressure on this issue. Major investments were made in water treatment plants in the Llobregat basin, so that by 2009 the more stringent EU limits were met (see figure 2). At the same time, a desalinisation plant which was being built in the Llobregat delta was also finished by 2009, after a severe drought

in 2007–2008. These new facilities seem to be able to meet the challenges posed by water quality and scarcity in the next decades for the city and its metropolitan area. Further, water consumption has been declining over the last years, due to lower industrial use caused by economic changes, greater use of the city aquifer by local services (for parks, watering sidewalk trees, summer street flushing . . .), and public education to reduce domestic consumption. The current consumption of water is down to a daily average of 108 liters per resident, a historic low.

Air Quality

Climate change is likely to result in worsening air pollution, as less precipitation and more heat may impact particle and ozone levels. Also, the expected increases in wildfires, which may be greater in area of urban and wildland interface,[11] may impact air quality, as shown repeatedly in California, and in Moscow in 2010.[12] In Barcelona, over the last decades air pollution has improved greatly. The causes for this change have been the economic changes leading to polluting industries closure or moving and to the fact that coal is no longer used as a source of energy. Among the monitored pollutants, particulate matter and NO_2 have posed problems. Although both are related closely with vehicle traffic, other factors influence their level. The trend has been favorable concerning PM10, levels for which have been within the European Directive requirements in the last years (and PM2.5 never exceeded the standard expected to be in force in the year 2020); the concentrations of NO_2 in some monitoring stations located in heavy traffic areas have exceeded them, but the trend is favorable. Figure 3 shows these trends over the last years, with a scheme that allows for the assessment of trends over time and which has been used elsewhere.[13]

Although many of the service vehicles in the city are switching to low pollution technologies (natural gas for buses and taxis and hybrid engines for taxis), a large share of motor vehicles in the city use diesel engines, which have been shown to be a major source of NO_2. A major reduction in the use of motor vehicles was expected from the expansion of the subway and train systems in the metropolitan area, but this has been slowed by the economic recession.

The expansion of the metropolitan urban system has been always faster than the expansion of mass transportation. Besides, political rivalries between local, regional and central governments may not have favored the development of mass transportation systems in the Metropolitan Area, which is largely beyond the responsibilities of the city government. Thus, although City residents use motor vehicles very little in daily life, thousands of persons commuting daily need to use private cars. The city has a large motorcycle fleet, favored by the climate. At the same time, the city has favored the use of bicycles, and a bike rental system has been in operation since 2007. Also, low speed zones (<30 km/h) within the City have expanded, and parking policies tend to raise the cost of motor vehicle utilization, and thus discourage it.

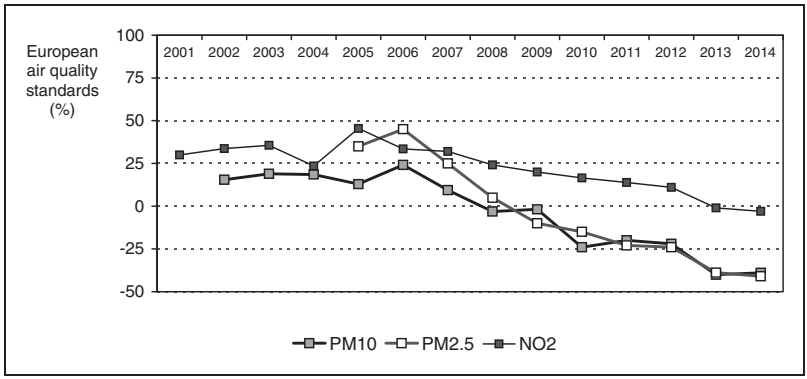

Figure 3. Levels of major air pollutants as percentages of air quality standards. Barcelona, 2001–2014.

Source: official monitors in the city, as collected by the Public Health Agency. Levels are the average of mean annual levels provided by all valid monitors for the year. $PM_{2.5}$ began to be collected in 2005. Standards are current standards for EU, except for $PM_{2.5}$ where the EU 2020 standard has been applied (NO_2 40 μg/m^3; PM_{10} 40 μg/m3, $PM_{2.5}$ 25 μg/m^3).

Diseases Transmitted by Vectors

Mosquitoes as vectors are a concern in Barcelona. Warming means more breeding opportunities: the duration of a breeding cycle shortens, the warm period extends, and there are more breeding cycles within the warm season. Thus the mosquito population may grow exponentially. As imported cases of diseases transmitted by mosquitoes are present, the potential risk of autochthonous transmission grows.

In the past, *Aedes egypti* was endemic in Spain; it was eliminated in the mid XX century, but may well be reintroduced. Besides, globalization has turned *Aedes albopictus* into an invading species, introduced in Spain (near Barcelona) in 2004 and expanding all over the coastal shore. It may be an effective vector for arbovirus and other diseases transmitted by mosquitoes. There are different species of Anopheles in Spain, among them *Anopheles atroparvus*, which may be an efficient vector for *Plasmodium vivax*; thus, a potential risk for the reintroduction of malaria in Spain exists, although it is believed to be low.[14]

Over the last decades, globalization trends have also brought more international travel to and from endemic areas for malaria, dengue or chikungunya. Foreign-born residents in the city have risen from 2% in 1996 to 17% in 2014.[15] Tourism has become a major economic activity: the supply of hotel rooms has risen from 10,000 in 1990 to 38,000 in 2014, and other lodging options have also grown.[16]

The city pest control services ascribed to the Public Health Agency began in 2005 a mosquito surveillance program after *Aedes albopictus* was identified in Catalonia. Although the risk for arbovirus transmission has been considered

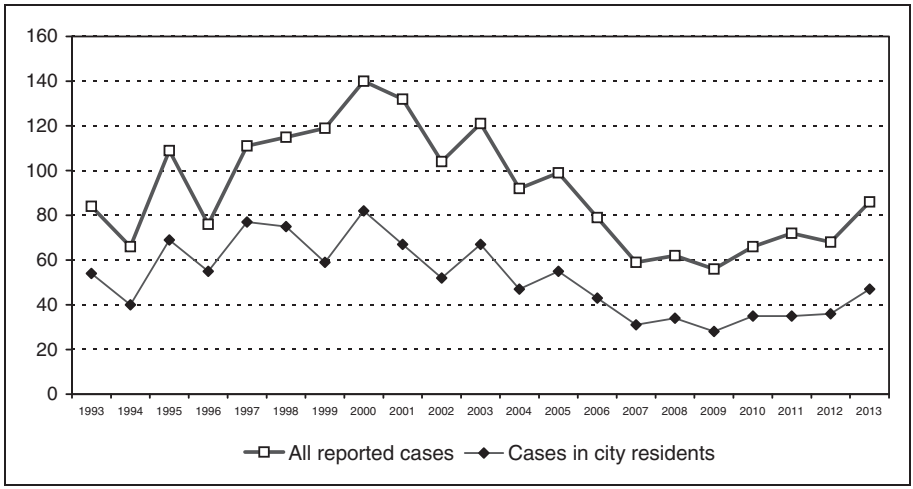

Figure 4. Reported malaria cases in the city, by residence status. Barcelona, 1993–2013. Source: Epidemiology service, Agència de Salut Pública de Barcelona.

low,[17] over the last years the Agency has made an effort to enumerate areas with greater mosquito breeding potential, and developed plans to reduce them. At the end of 2014, there were 68 spots in the public domain identified within the city as posing relevant risks. In the summer of 2015, a new smart-phone application allowing citizens to report on mosquito presence (http://www.mosquitoalert.-com/) has brought a new source of surveillance. Coordination has been secured with the relevant divisions of the city administration to act in places considered to pose high risk of mosquito breeding. While efforts have been largely fruitful for ornamental fountains, the identification of spots in the storm drainage system with high breeding potential will need research and piloting of novel schemes to address it.

Historically, malaria was endemic in some parts of Spain, but was eradicated: the last autochthonous case was reported in 1961. Imported cases occur, and in Barcelona the reported cases of malaria in city residents from the 1990s to the present have fluctuated yearly in the 40-80 range.[18] Figure 4 shows that for the last years there has been some increase (although not to the levels seen before programs and clinics were established for travelers).

The Division of Epidemiology of the Public Health Agency has maintained surveillance on arbovirus and malaria. Before 2014 dengue and chikungunya cases were investigated as rare events, but since then they have become part of the mandatory reportable disease surveillance system (as malaria has been for decades). All reported cases are investigated. Joint work has been undertaken with the pest control service to ensure enhanced vector control in the vicinity of cases. Thus, of the 70 reported cases of imported arbovirus disease in 2014, 29

were assessed as viremic by epidemiològic investigation (30% of dengue cases and 70% of chikungunya cases); the inspection of residences identified the presence of potential vectors in 7 cases.

Although all the malaria and arbovirus cases reported have been imported, in recent years in Spain there have been cases of transmission both of malaria (one case in the province of Huesca, Aragon, in the fall of 2010), and of chikungunya (one case in Gandia, Valencia, in the summer of 2015). Autochthonous dengue cases have been reported from nearby France.

Other Cross-Sectional Issues Relevant for Public Health

Vulnerable populations. Analysis of the adverse health effects of climate change have shown that some population subgroups are particularly at risk. They include mostly the frail elderly, particularly those living alone, as well as the socially disadvantaged. Critical analyses of heat wave warning systems have found that the frail elderly may not respond to such interventions as expected.[19] Data show that in Barcelona having air conditioning at home is limited (27% of those 65 years or older), and wealth is probably the major mediator.[20] Studies developed in Barcelona have confirmed that among the factors related with higher mortality during heat waves deprivation and advanced age are both key variables.[21,22]

Urban green space. The greening of cities is considered to be a major strategy to confront climate change in urban settings, reducing the heat island effect and with a potential role in pollution abatement. Studies in Barcelona have shown that urban green infrastructure may play a relevant role reducing PM_{10} levels, but not for NOx.[23] It is crucial for mitigation, but it also has many co-benefits for health. It may also have the potential to improve adaptation, as more vegetation may be linked to reducing temperature, although the existing evidence on this topic is weak and more research is needed.[19] The city of Barcelona has undertaken important efforts in expanding the number and surface of green spaces, and the presence of trees and vegetation in sidewalks and paved areas. Figure 5 shows the evolution of the surface of urban green space in the city: since 1997 the green surface has increased by 6.7%.[24] Expanding green surface within the densely built city limits is not an easy task. After years of increasing the presence of trees in sidewalks and squares, in recent years the city administration has experimented with several vertical gardens, with mixed results. It is now piloting innovative schemes for a mosaic integration of green roofs with solar energy technology and rainwater collection in a few city buildings.

Infrastructure vulnerability. Key infrastructure facilities have been built in the Llobregat river delta (Barcelona's El Prat international airport, a wastewater treatment plant, and a marine water desalination plant) and the Besòs river

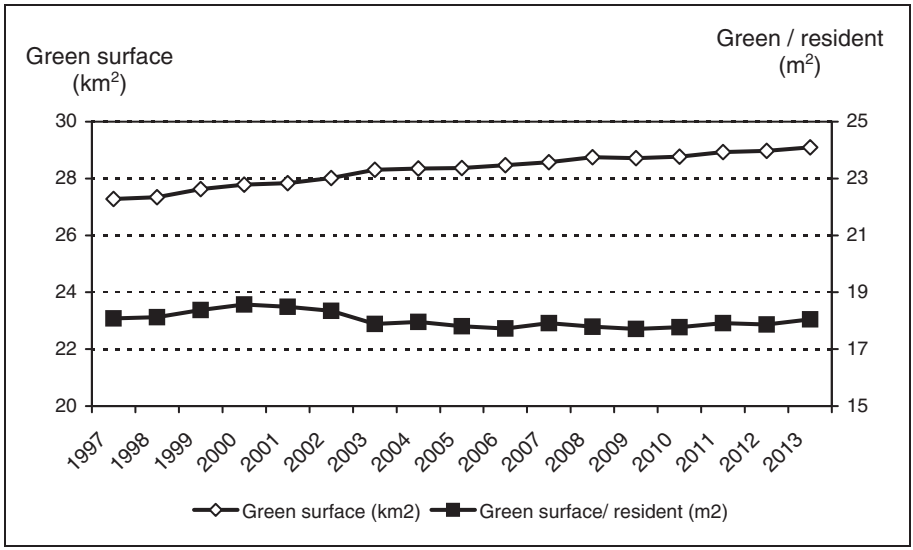

Figure 5. Trees and urban green space in the city. Barcelona, 1997–2013.
Source: Habitat urbà, Ajuntament de Barcelona, 2014.

mouth (a wastewater treatment plant, an urban waste cogeneration plant, a convention center), and thus potentially subject to risks derived from climate change. Besides the port, a key element of the city infrastructure, a major hospital is also in close proximity to the sea.

Governance and Resilience

As has been explained previously, the city administration has been implementing actions aimed at a sustainable city for decades, starting with the Local Agenda 21 since the 1990s. The planning process has been guided by participatory strategies in its development. The energy plan, spanning the 2011–2020 period and going beyond the city limits to the metropolitan area and its key infrastructure, also covers the issues of climate change and air pollution. This plan is in fact currently the key reference document in terms of mitigation planning. Other relevant plans are the city air pollution abatement plan, the urban mobility plan, and the municipal plan to enhance urban greening.

In the summer of 2007, three related events gave high visibility to the vulnerability of Barcelona's infrastructure: problems in improving train infrastructure, a severe drought, and an electricity blackout which caused several components of the energy supply to fail successively. These events generated political and media disputes, and brought to the forefront the need for a systematic analysis of key infrastructure, including water and electricityl supply, which was

subsequently undertaken. Since 2009, a variety of temporary task-forces were organized, bringing together different actors to confront key vulnerability issues, developing specific projects to reduce and monitor them (called Urban Resilience Boards).[25] This effort brought in fact a paradigm shift in governance. Based on the perspectives of both risk management and cost-benefit analysis, it requires flexibility adopting solutions (given the uncertainties of any forecasts), and a multiple scale and intersectorial approach.

Recently, Barcelona's Commitment to the Climate, a declaration prepared with wide participation from the civil society and including seven key projects led by the city administration, was approved in late 2015 and presented by the Mayor to the 21st Conference of Parties to the United Nations Framework Convention on Climate Change, held in Paris. Accordingly, following some previous work involving the analysis of what other major cities in the world have done to confront climate change, the city administration is currently in the process of preparing its first adaptation plan to deal with climate change. It is being built with an intersectorial aproach involving different departments of the city administration and other relevant agencies, as well as the district administrations; this plan covers resilience and adaptation to climate change. As shown in table 1, most of these efforts involve key actors in the Catalan and local administrations, but the public health services also play a relevant role in the process.

Main Challenges for the Future and Next Steps

From a public health perspective, the main issues to address in the future are those listed in table 1. A key issue is maintaining progress to reduce emissions; this is a contribution to the mitigation of climate change, but lowering air pollution has other beneficial effects, or co-benefits, for health. Protecting key infrastructure for the city, including health facilities, and ensuring they can meet the demands in a changing climate context is another crucial topic. At the same time, adapting surveillance services to the changing demands in the field of vector-borne disease and vector control is most relevant, and will require an increase in the resources allotted to this task.

A pressing issue will be to ensure the operational aspects of heat wave plans. This may involve more accurate mapping of vulnerability, and evaluations of the targeting and coverage of warning systems and of to what extent the most vulnerable populations respond in ways that effectively decrease their risk. Monitoring behavior, observational studies and long term impact evaluations should provide data that may be used to improve systems.

Developing models to forecast events may be another relevant action. On one side, forecasting climate and the effects of alternative options may be useful to raise public awareness and to facilitate change towards mitigation and adaptation strategies. On the other side, modeling aspects such as vector populations

Table 1. Selected aspects related with climate change posing relevant issues for public health, major actors involved, and role of public health services. Barcelona, 2016.

Aspect	Major actors	Role of public health services
Air pollution	Mobility and Infrastructure Div. Metropolitan Transport Authority Dept. of Environment	Measurement and assessment of air pollution levels. Supporting emission abatements plans.
Water availability and quality	Dept of Environment. Water Agency of Catalonia.	Measurement and assessment of water quality.
Health care facilities	Catalan Health Service. Hospital del Mar.	Supporting resilience awareness
Vector-borne diseases	Public Health Agency. Urban Services Div. Parks & Gardens Div.	Surveillance of vector-borne diseases, prompt investigation of reported cases. Surveillance of vectors around reported cases. Vector abatement in the city. Identifying spots at risk for vector breeding and fostering control action. Empowering and educating the public about vector control.
Heat waves	Catalan Health Service Social Services Div. Public Health Agency	Supporting warning systems. Monitoring deaths during alerts. Evaluating heat wave warning systems.
Reducing heat island effect	Parks & Gardens Div. Urban Planning Div.	Supporting interventions and their evaluation.

Div. refer to Divisions of the city administration; Dept. refer to Departments of the Catalan administration.

each season may be crucial to secure the proper responses and to avoid critical situations, as suggested by experiences in other cities.[26]

Promoting initiatives to reduce the heat island effect in the city may be another key contribution of public health services. While the actual implementation of such initiatives will be outside the domain of public health services, they may provide the needed evaluation capacity if involved in such intersectorial projects. Key issues here will be monitoring how some interventions are actually able to have an impact on physical outcomes such as temperature, and whether they are able to translate this change into human health measures. This could be done at the micro level, experimenting with options in single buildings or blocks, but also at a meso level in selected neighborhoods.

Conclusions

Having had to confront in recent years specific issues posed by events caused or exacerbated by climate change, Barcelona is now better-prepared for the challenges posed by it. In particular, water availability and quality were

pressing issues that required major investments, eventually leading to an improvement of the existing infrastructure in Barcelona. The strategies to confront air pollution have also been deployed as the demand for cleaner air has risen, and public awareness of the situation and of its causes has been growing. In fact, climate change has not been addressed by public health services as a stand-alone issue. Nevertheless, adaptation efforts are apparent. This has also been documented in other settings,[27] and may partially respond to European Union regulations. However, these efforts may not be visible and apparent to an external observer, as suggested by their invisibility to critical reviews in the published literature.[28]

Regarding heat preparedness, the summer of 2003 heat wave in Europe was a turning point. That year, after a mild influenza season, persistent high temperatures were associated with large mortality increases, concentrated among the frail elderly. This was documented in France, Spain, and other countries, and specific studies quantified its magnitude in Barcelona. Consequently, heat wave warning systems and plans were developed, and have been in operation ever since. Their rigorous evaluation, beyond the usual administrative report, remains a challenging task to be done (in Barcelona and in other cities as well). Such evaluation should point to specific actions aimed at improving their effectiveness.

Public health services have anticipated emerging risks derived from climate change and prepared for vector-borne diseases. Surveillance services have proven their capacity to respond to such events, but may be overburdened should its magnitude increase in the next years. Vector control actions can be anticipated to reduce the risks posed by warming. Planned action should be preferred to reactive responses in this field, as the recent alert caused by the zika virus infection shows.

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