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A Description and Analysis of Mediterranean Cities and Regions Planning for Climate Impacts

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A Description and Analysis of Mediterranean Cities and Regions Planning for Climate Impacts

The current literature on local climate change adaptation contains comparatively little research into local and regional adaptation to climate change, and few comparisons of local climate adaptation initiatives across broad climate regions. Our conjecture is that areas with similar climates will face similar sets of climate risks and therefore can share adaptation solutions. This paper examines 36 adaptation plans (cases) selected from across the five Mediterranean climate regions in order to find if there is evidence that groups of cities and/or regions share similar responses to climate risks. We examined adaptation strategies for sea level rise, increased temperatures, flooding, reduced water supply and drought, wildfires, extreme weather events, and increased GHGs and air pollution. We examined the cities' adaptation plans and categorized them into four stages: training, assessment, recommendations, and implementation. A contribution of the paper is a new way of analyzing adaptation by building a matrix of adaptation policy stage and climate impact area that shows which policy options have advanced from planning to implementation in our cases. We found that a wide variety of cities have completed assessments in one or more of the climate adaptation areas. Our major finding is that these Mediterranean cities often have quite similar plans for dealing with several climate risks. Many cities are planning stormwater runoff infrastructure overhauls in order to ameliorate the impacts of climate-related water supply and flooding effects. Similarly, many cities are proposing greening strategies to deal with heat island effects. Finally, we observe that the adaptation plans imply large cross-cutting infrastructure investment with their concomitant financial demands. We also observe a common gap, that while retreat from threatened areas is likely to be a necessary strategy for sea level rise, flooding, and perhaps wildfire, retreat is seldom mentioned, and not at all at the implementation stage. The key contribution of this paper is to provide a starting point for researchers and policymakers to consider the similarities and differences in adaptation approaches across Mediterranean climate zone cities. This paper establishes a baseline for adaptation policy in our urban cases that additional research can use to examine adaptation progress moving forward.

Keywords
Adaptation, Infrastructure, Policy, Local

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INTRODUCTION

The climate mitigation commitments from the United Nations Framework Convention on Climate Change (UNFCCC) 2014 Conference of the Parties "COP 20" in Lima are unlikely to hold average global temperature increases below 2 degrees Celsius (Rogelj et al., 2011). This implies that even with aggressive climate mitigation efforts in place, populations worldwide will be exposed to climate hazards brought on by rising temperatures (Noble et al., 2014). Nations, regions, and cities are responding to this climate change reality with adaptation measures. Successful adaptation to climate change will need to consider local environmental and socioeconomic factors as well as the changing climate. In this paper, we make the case that the particular characteristics of the Mediterranean climate zone indicate that localities there have a similar set of adaptation challenges.[1] This suggests that Mediterranean climate zone areas can learn from each other's adaptation plans, policies, initiatives, and projects. This paper seeks to determine which Mediterranean-climate cities are addressing climate change impacts (e.g., sea level rise, wildfires, etc.) using similar adaptation approaches. The goal is to provide adaptation stakeholders and policy-focused researchers with a resource to learn about Mediterranean-climate cities working on common approaches to these problems so they can benefit from other cities' adaptation experiences.

Local policymakers and other stakeholders often want detailed information to determine whether policies pursued by similar cities are transferable and/or share characteristics with the ones they are considering. Therefore, we collected plans with in-depth descriptions of adaptation strategies for a limited number of urban areas (36 regions, see Appendix B: Table 1) across the Mediterranean climate zone. For these cities, we use existing reports (e.g., adaptation plans) to examine trends in adaptation planning and action. As part of the effort to clarify these policies for stakeholders, we categorize policies along two axes: (1) primarily government-led versus those relying more on individual, voluntary action such as information provision; and (2) whether policies are planned or have proceeded to implementation.

Climate Adaptation is Local

Carmin and colleagues (2012) find that only seven percent of cities believe that their national authorities understand their adaptation realities; this may be due, in part, to the heterogeneity of climate and ecosystems (e.g., agencies in wet, marshy, Washington, D.C. may not understand the realities of San Diego's Mediterranean climate). Different geographic areas experience varying climate change impacts depending on existing climate and geography (e.g., warmer areas may experience greater air-conditioning and thus energy demands due to climate change and colder areas may experience a net energy savings from warmer winters (Watkiss, 2007). Also, dissimilar areas may not have the same vulnerabilities (based on their populations, levels of wealth, and infrastructure). These two observations jointly imply that adaptation (vs. mitigation) is primarily a local, heterogeneous activity (Kittinger and Ayers, 2010). Further, climate-change adaptation challenges are often based on the exacerbation of existing ecosystem difficulties. For instance, climate change will decrease the accumulation of snow in the Sierra Nevada mountain range in California and thus magnify California's existing water shortages (Vicuña et al., 2007).

1 Zones Csa and CSb in the Koppen classification.

The local heterogeneity in climate threats implies that local governments bear the primary responsibility of adapting to climate change (Field et al., 2012; Hurtado et al., 2015). National and international bodies seldom have the information to plan and react to dynamic, heterogeneous climate impacts. Also, local governments are likely to already have significant experience with reacting to risks (e.g., flooding, heat waves, and storm surges) that are magnified by climate change. Adaptation planning is likely to be affected by such experiences and histories (Cutter et al., 2010), and these experiences are likely to be similar within the Mediterranean climate zone. This reasoning and prior literature suggests that local governments are the primary locus of climate adaptation and has led us to focus on cities.

Ecosystems and Adaptation

Previous work on urban sustainability indicates that policymakers and researchers should understand climate adaptation via an ecosystem service lens, since the human impacts of climate change are not discrete and separate from the consequences of other ecosystem service crises. Jansson (2013) discusses the utility of evaluating urban sustainability and resilience via an ecosystem services framework). For instance, (i) climate-induced drought will have more severe consequences in regions with preexisting depletions of groundwater; (ii) SLR (sea level rise) will do more damage in areas where the depletion of coastal aquifers has promoted vulnerabilities associated with ocean intrusion (Rotzoll & Fletcher, 2012), and (iii) increases in fire damage, due to climate change, are exacerbated by development in the Wildland-Urban-Interface (Theobald & Romme, 2007). For these reasons, past environmental challenges in a locale will significantly govern adaptation measures to a large extent.

Biomes will also tend to share these environmental challenges (e.g., the similarities of Mediterranean regions—in terms of precipitation, native vegetation, and temperature—means that there should be similarities in adaptation processes due to similarities in ecosystem services and deficits.) In particular, urban areas in the Mediterranean climate zone, because of their hot, dry summers, share a similar set of risks from drought, flood, and fire. Also, the subtropical locations and their consequent hot summers means they are at particular risk from further heat extremes. Finally, Mediterranean climate zones are largely coastal and therefore are more exposed than other climates to sea-level rise. Many climate zones share one or a few of these risks, but the full set of risks is more characteristic of Mediterranean cities than those of other climate zones. This means strategies that may work for another climate zone may backfire if moved to another area. For example, cities in a hot climate with year-round rainfall can safely plant trees to mitigate heat island effects. Mediterranean cities will need to contemplate whether the extra water demand from those trees can be met, and whether they pose a fire hazard. This example shows how the full set of environmental challenges must be considered for appropriate adaptation and the risks of transferring adaptation practice across climate zones.

The similar adaptation challenges mean that policymakers and researchers can learn more from cities with Mediterranean climates than those that do not have such climates. Hunt and Watkiss (2011) also call for case studies focused on similar areas for these reasons. Tompkins et al. (2010) discusses the importance of the inclusion of learning mechanisms in adaptations. A key aim of this paper is to document areas where cities are planning and undertaking similar projects in similar climate zones precisely so that this learning can take place via future research and evaluation.

Local Adaptation in the Literature

The adaptation literature indicates some adaptation areas on which to focus. There has been a great deal of research on what adaptation should look like, (i) in general (Neumann et al., 2010 and Chambwera et al., 2014); and (ii) for SLR in particular (Smit & Wandel, 2006). There are fewer studies on current adaptation efforts (especially at local levels) and only one we could locate that looks specifically at the Mediterranean climate region (Hurtado et al., 2015). Carmin et al. (2012) find that cities collectively view storm-water management (65% expect impacts) and non-water infrastructure (41% expect impacts) as the most significant concerns associated with climate change. Loss of natural systems and drought management are also commonly viewed as threats. Fire threats are more common in the Mediterranean climate zone than worldwide (Matteucci et al., 2013), Therefore this is a natural issue to include in our review. This literature gives us a starting point for our list of issue areas: (1) SLR; (2) increased temperature effects including urban heat islands and wildfire; (3) water cycle changes including flooding and drought; and (4) adaptation aspects of energy supply and air pollution.[2]

The literature emphasizes two key types of responses to climate-change threats: (1) direct response to direct threats (e.g., a retreat from the shore or the building of a dike in response to SLR); and (2) a more general socioeconomic response. Much of the literature (see Hunt and Watkiss, 2011) emphasizes dangers to vulnerable populations. One way to plan for adaptation is to support these populations (e.g., economically, politically, and socially) so that they are better equipped to adapt.

This paper emphasizes direct responses to climate threats since they tend to be emphasized in city planning documents. We find that some urban responses emphasize improving the capacity of vulnerable populations; however, these are in the minority in the documents we have reviewed. This is consistent with the literature on national adaptation, which finds that there are relatively few adaptation actions associated with vulnerable groups (Lesnikowski et al., 2013). However, our literature review approach may not fully capture these types of policies and further research should thus consider whether indirect responses are found in other policies.

In this paper, we begin by discussing the characteristics of the Mediterranean climate zone. Then, we discuss our process for generating our plan comparisons. Next, we cover each of the climate adaptation challenges listed above (throughout these sections we just refer to cities, rather than a wordy phrase such as "cities in our sample"). Our aims are twofold for each of these challenges: (1) describing for which adaptation policies or projects there is a significant group of cities planning or implementing the policies; and (2) the general thrust of planning and the implementation stages for the different cities. These are both critical pieces of information for the practitioner/researcher as they indicate where and along what lines cooperation may be useful. We also pull out some of the significant cases in each section and show how these

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2 This last category we added after seeing the extensive coverage in many adaptation plans.

adaptation plans may be useful in other cities. We conclude by identifying the areas that strike us as particularly useful for comparison and cooperative research.

The Mediterranean Climate Zone

The key Mediterranean climate zone geographic areas are: the Mediterranean Sea littoral itself, Chile, California and Baja-California, southwestern Australia, and South Africa. However, the Mediterranean Sea portion is about twice the size as the other climate zones put together. Therefore, in order to investigate the possibility of collaboration across distinct areas, we sought to find adaptation plans in North Africa, the eastern Mediterranean, and the eastern and western portion of the northern Mediterranean coast. This categorization reflects that the different historical and economic trajectories of these various areas could inhibit actual cooperation (for instance, North Africa is not in the E.U.) but, on the other hand, could enhance the potential benefits of cooperation because of the different experiences, histories, and perspectives the different regions bring to adaptation.

The Mediterranean climate, moderated by cool offshore ocean currents, is characterized by hot, dry summers and mild, rainy winters. The regions sharing these climate characteristics are located roughly between 30 and 45 degrees latitude on both sides of the equator and represent less than 3% of the world's land area. However, despite being a relatively small percentage of the world's area, they contain globally important resources and infrastructure. For example, they encompass biodiversity hotspots with 20% of the world's total plant biodiversity, including over 26,000 endemic species. Underwood and colleagues (2009) state that it is also one of the world's most endangered biomes. Additionally, these regions are made up of subnational jurisdictions (i.e., cities, states, provinces) that are strong economic centers with growing populations and tourism as a key driver. For instance, if California were its own nation, it would be the sixth largest economy in the world placing it ahead of both France and India (Perry, 2016).

The attractive Mediterranean climate (and culture) has led to economic and population growth that threatens biodiversity and ecosystem services. Underwood et al. (2009) finds that population density across the biome increased by 13% from 1990 to 2000, and undoubtedly has increased more since. In addition, they find that urban areas have grown by 13% and some types of agriculture, such as vineyards, are also growing quickly. This growth is fairly consistent across Mediterranean areas, from 11% in already dense California to 19% in Chile. This implies that climate adaptation across the Mediterranean biome must also occur in the midst of rapid urbanization.

METHODS AND DATA

City Selection and Policy Description

The aim of this study is to investigate whether and in what policy areas there is significant commonality in adaptation plans and projects across the Mediterranean zone climate regions. We investigate whether our hypothesis that there is a critical mass of cities in this climate zone working on similar adaptation projects – even when as geographically distant as Los Angeles and Athens – bears out after examining the plans. We began this research with a broad search that focused on the larger Mediterranean cities[3] and sought to find those with detailed descriptions of projects in each of the regions detailed in the previous section (Appendix B: Table 1). We completed the research by the end of 2013 and sought plans dated on or after 2005.[4] We concentrated on finding in-depth plans in each region so that we could do detailed policy comparisons to find if these areas were confronting similar challenges. Our search turned up a multiplicity of adaptation planning approaches where plans might be authored by a city, a regional entity, or a municipal agency and which might consider addressing a single risk rather than multiple risks. We chose to use a case study approach for examining very detailed plans across the different areas within the climate zone rather than a representative sample approach that would have to restrict itself to a subset of these planning approaches. We initially conducted Internet-based searches to identify materials related to climate adaptation (in English and Spanish); however, many regions did not have documents detailing such climate-change adaptation efforts. This may be due to the (i) incorporation of adaptation efforts in other planning documents, (ii) decisions to not post such materials online, or (iii) the posting of such documents in different languages (i.e., other than English and Spanish). Thus, this does not imply that these areas are not conducting such planning. Our sample is not representative and therefore cannot be used to draw conclusions about Mediterranean adaptation in general. Instead, we examine the smallest set of projects and policies for which a significant number of cities are planning.

The broad survey conducted by Carmin and associates in 2012 involving 468 cities on climate adaptation helped clarify some of the data associated with our sample of urban and regional plans. They found that (i) approximately 68 percent of cities worldwide report some kind of adaptation planning (e.g., informal meetings), (ii) 21 percent of cities are working on plan development, and (iii) 18 percent of cities are engaged in some implementation. In this study, the cities are often in advanced stages of planning or implementation, so they are (i) in a group comprising probably less than a fifth of all cities (if the Carmin et al., 2012 sample is considered representative), and (ii) likely at the leading edge of climate adaptation. This is intentional because our aim is to go in depth into the particulars of climate adaptation policies. The Carmin survey is valuable due to its (i) broad view of city adaptation activities, and (ii) focus on the political and governance aspects of climate-change adaptation. This paper seeks to complement this approach by closely examining specific policy responses that cities are planning or implementing in response to the key threats associated with climate change.

We use existing reports (e.g., adaptation plans) from cities and regions to investigate and categorize planning for the seven major threats from climate change detailed earlier. This is not an exhaustive list of climate impacts; however, it does cover most of the major impacts currently of interest to Mediterranean cities and regions that we found in our literature review and in our discussions with many actors. We then categorize cities along two vectors that we think will be particularly useful for stakeholders across cities who wish to work with one another: (i) their

3 We also include Melbourne, Australia, which borders but is not in the Mediterranean climate zone (largely because it does not have dry summers). One reason for this inclusion is that climate zones in southern Australia are quickly becoming drier and their climates may become much more like a Mediterranean climate in the future (Mahlstein et al., 2013. Another reason is that Melbourne's adaptation plans are very thorough and its climate zone is currently close enough to that of the Mediterranean such that it faces similar issues.

4 Undoubtedly, there have been many other plans released since that period but research like this needs a cut-off date if it is ever to be completed.

progress in responding to the threats and (ii) the types of responses (e.g., government-led or bottom-up actions) to each threat.

Similar to an earlier study (Tompkins et al., 2010), we roughly categorize this study's cities and regions into four planning categories; however, the earlier study breaks adaptation actions into more categories because of its focus on drivers of adaptation action. Our first two stages are "planning-to-plan" stages. In Stage Zero, cities have not done any specific adaptation planning; however, they (i) have recognized this need, and (ii) are training their personnel to begin climate planning. Stage One involves evaluating and assessing potential risks; however, actual planning is not yet occurring. In Stage Two, cities have begun making recommendations to undertake certain adaptation actions; however, they have not begun to undertake them. In Stage Three, the cities are implementing such actions (e.g., building infrastructure and changing policies).[5]

One key difference in policies is the placement of the responsibility for adaptation decisions: (i) persuasion policies (i.e., with information or monetary incentives for individuals and firms) that rely on individual voluntary changes in behavior, as opposed to (ii) primarily government-led policies such as infrastructure development and regulation.[6] In particular, the identification of infrastructure efforts is important for both adaptation and impact evaluation. Hsiang and Jina (2014) document how storm impacts lower economic growth and suggest that the impacts on infrastructure—and the financial demands of rebuilding infrastructure—are part of the story behind the comparatively low economic growth of nations which experience significantly greater storm-related losses. The second key government-led category is direct regulation such as zoning or building requirements that typically relies on uniform mandates. We categorize these separately from infrastructure.

Persuasion measures (e.g., informing the public of cooling centers during heat waves) are policies that attempt to alter individual behaviors and generally assume that only a portion of the population will respond (as opposed to universal and mandatory regulation such as building requirements.) There is a continuum of persuasion measures from simple information to altering prices in order to influence individual choice. Price-based measures (e.g., increased water prices or insurance requirements) represent a stronger push toward individual adaptation (vs. pure information campaigns); however, they still rely on influencing individual decision-making rather than mandating it. Often these policies provide a lower-cost adaptation option that will be attractive to governments with fewer resources.

A key contribution of this report is the detailed categorization and description of policies in the three categories of infrastructure, regulation, and persuasion. First, we completed a detailed categorization of policies in each area. Then, we rechecked each listed policy to verify our first listing and grouped the detailed categories into those of supplementary tables. Then, we

5 We don't include cities where we don't observe adaptation documents because those cities might have their adaptation plans integrated into a higher level of government (or elsewhere).

6 Tompkins et al. (2010) summarize the types of responses slightly differently (e.g., they use information and public goods provisions as their two categories). These map pretty closely; information goes in our *persuasion strategy* and most public good provision is in our *government-led* category. However, we are more interested in how governments are going about adaptation planning; thus, incentive-based methods and information are grouped together under *persuasion strategy*.

hired research assistants to double check each listed policy and verify its placement in each report and its categorization. This detailed categorization will assist stakeholders who want to locate cities that are pursuing policies in which they are interested. This also provides a foundation for future research as now these policies can be tracked to see how they evolve in future adaptation reports from these cities.

Sea Level Rise

Rising sea levels are a common problem faced by coastal cities worldwide and are thus frequently addressed in the climate-adaptation strategies of coastal cities. SLR not only poses a number of risks to coastal cities but can also affect cities further inland if they are situated on a tidal watercourse (e.g., Belmont, Australia[7]). Some of the potential risks associated with SLR include:

- storm surge, flooding, and tsunami risk;
- inundation of low-lying areas and associated losses (e.g., of biodiversity and human displacement);
- subsidence;
- coastal erosion;
- saltwater intrusion into aquifers and wells (which could contaminate drinking-water sources); and
- water-table rise (and associated flooding risks).

SLR adaptations will require significant infrastructure investments. Neumann and colleagues (2011) have reviewed optimal SLR adaptations for the U.S. (with the objective of determining the categories and costs of adaptations that will need to be undertaken). They found that the costs are higher than previous estimates (e.g., $63 billion for a mid-range Intergovernmental Panel on Climate Change [IPCC] SLR projection). However, they only counted direct construction and maintenance costs. Nevertheless, the ecological and aesthetic costs of fortifying that much coastline would be large as well (Berry et al., 2013).

Most of the affected cities recognize marine submersions (due to storm surges and flooding) as key impacts of SLR. Certain North African cities (e.g., Tunis, Casablanca, and Alexandria) have also identified large waves (e.g., tsunamis)—which may form as a result of earthquakes or landslides occurring on the ocean floor—as potential risks in their climate-change adaptation documents (World Bank 2011). This joint planning for related risks demonstrates how such adaptations can complement planning for other natural dangers.

SLR can also combine with other climate impacts (e.g., drought and flooding) to create additional, synergistic problems. A rise in sea level will force underground saltwater further inland, which will result in (i) saltwater intrusion into aquifers and wells and (ii) contamination of drinking-water sources (Ketabchi et al., 2016). This intrusion will also cause the water table to rise and thus create a risk of flooding, especially in unconfined shallow aquifers (Discussed by San Diego SLR, Rotzoll & Fletcher [2012]). Moreover, when SLR is combined with flooding (as

7 The adaptation reports are listed at the end of this paper in alphabetical order for convenience.

a result of storm surge or due to heavy rainfall), the degree of flooding can be exacerbated significantly (Rotzoll and Fletcher, 2012).

The following cities have identified SLR as a potential risk. These cities are in various stages of SLR preparation and adaptation (as outlined below).[8]

Table 1. Mediterranean Cities' Sea Level Rise Adaptation Stages.

Adaptation stage	Region/City
Total	22 out 36 plans
Stage 0: Training	Algiers and Zadar
Stage 1: Assessment	Ancona; Zadar (undergoing training but have assessed SLR to be a risk factor), Almada and Barcelona
Stage 2: Recommendations	Cities: Alexandria, Casablanca, Tunis Cape Town, Cyprus, Gibraltar, San Diego, and Tel Aviv Regions: Catalonia, Israel, Palestine, South Australia, Western Cape
Stage 3: Implementation	Cities: Belmont, Los Angeles (Airports), Melbourne Regions: California

Cities in the second and third stages of planning have all put forward recommendations and options to deal with SLR-related threats (e.g., flooding, inundation, and an increase in the water table). We divide these into our previously discussed categories of infrastructure and hard planning (zoning or strong building requirements) and persuasion and information strategies. (Table S-1 in the supplementary materials contains more details on the types of actions cities are taking.)

SLR (vs. other climate impacts) is relatively easy to predict. Furthermore, most of the cities in Mediterranean climates are (i) near the ocean shore or (ii) dependent on coastal services. Thus, we expected that SLR would be one of the areas where we see the most advanced planning; however, few of the cities are at the implementation stage.

This study (see Table S-1, all "S" tables are in the supplementary material) finds that implementation measures associated with Stage Three cities often (i) lean heavily on green (e.g., dunes, wetlands, and kelp beds) and grey (e.g., breakwaters and levees) infrastructure solutions, and (ii) upgrade wastewater, storm-water, and waste-disposal infrastructure that they expect to be degraded by SLR. In the following text box, we discuss Los Angeles Airports' plan to adapt to SLR by rebuilding coastal dunes, a green infrastructure measure. Since many of these facilities are located near sea level, they need to be moved or changed in response to SLR threat. (See the

8 The cities in Stage Two may not have recommendations for adaptation to all climate challenges but do have recommendations for some climate change threats. Similarly, cities in Stage Three are implementing some adaptation measures but often have long-term recommendations for others. We classify cities as Stage Three if they have a substantial body of measures that are being implemented.

text box for some specific examples.) We found a limited emphasis on persuasion and information strategies in Stage Three cities; however, some cities are working on plans to develop awareness of future SLR threat and its impact on insurance markets.

Sea Level Rise on the California Coast: Los Angeles Airports' Coastal Dunes Improvement Project.

In June 2013, the California Coastal Commission – a state agency that oversees land use and public access to California's extensive coastline – approved the Los Angeles World Airports' (LAWA) permit application for the implementation of the Coastal Dunes Improvement Project. The goals of the $3 million project were to both improve the aesthetics of the dunes as well as to plant native vegetation on 48 acres of the 307-acre site. LAWA said of the project that it was part of its commitment to environmental stewardship and an effort to meet the surrounding community's ecological, aesthetic, social, political and economic needs. As of July 2016, LAWA had spent the budget for the Coastal Dunes Improvement Project indicating that they had fully implemented it. (References in Appendix A).

Recommendations and options for Stage Two cities are more ambitious and wide-ranging (vs. the implementation measures associated with Stage Three cities); this is likely because planning in Stage Two often involves the consideration of myriad options (vs. following an established plan). Infrastructure solutions that protect or restore coasts, especially green solutions (e.g., extensive green infrastructure options that protect and rehabilitate natural buffers such as wetlands, estuaries, dune cordons, and kelp beds) are heavily represented among these cities (see Table S-1). A striking feature of Stage Two recommendations is the breadth of infrastructure issues under consideration. For example, myriad aspects of water infrastructure are being reconsidered in response to SLR in these cities (e.g., flooding, storm-water runoff management, wastewater management, building codes, and ports and dams). This list of preparation measures likely makes a good checklist for cities to consider in their adaptation efforts.

Stage Two cities prominently feature persuasive strategies (e.g., insurance, pricing, and information) more than Stage Three cities. Several cities discuss insurance market strategies in order to properly price the risks of SLR. In a similar vein, San Diego SLR and Tel Aviv are examining economic incentives that promote adaptation to anticipated climatic changes. Another frequent strategy is integrating SLR into spatial planning.

The academic literature on SLR emphasizes that retreat is a necessary part of adaptation strategy. Some Stage Two cities recognize this via extensive land-use recommendations, which include the implementation of coastal buffer zones, integrating SLR into spatial plans, establishing building set-back lines, and halting the reclamation of land that would be threatened by SLR (see Table S-1). Some cities go further and include "managed retreat" as an option for vulnerable coastal areas (see Cape Town SLR documents); however, (i) no mandated retreat strategies have yet reached an implementation stage and (ii) the retreat-related political controversies in New York City and New Jersey suggest that (a) these policies will be difficult to implement and (b) we should gauge whether (and how) zoning and building code strategies manage retreat (Fosset and Friedman, 2014).

Our review of SLR adaptation indicates that cities are considering a wide variety of adaptation measures that include both persuasive and infrastructure solutions. Cities likely have a great deal of information to share about their experiences planning and implementing coastal protection measures. Also, there seems to be a number of cities looking at insurance market changes and integrating SLR into planning. But beyond these popular categories, cities could likely learn from the breadth of strategies under consideration in this relatively small set of cities.

Increased Temperature

For multiple reasons, rising temperatures pose a climate risk that is particularly pertinent to city dwellers. First, buildings, transportation, and industrial activities generate “waste heat” within cities and increase temperatures (Hunt and Watkiss, 2011). Second, buildings further exacerbate this problem by reducing airflow and thus trapping heat within the urban environment. Third, urban environments tend to act as 'heat islands' that trap, absorb, and subsequently radiate heat from pavements, roads, and buildings (Phelan et al., 2015).

Heat waves can cause lack of productivity and heat stress, and, in severe cases, can result in significant increases in mortality (Gosling, 2009) (e.g., the estimated 71,000 deaths in the 2003 European heat wave).[9] The Melbourne, Australia adaptation document describes how heat waves can lead to cascading consequences (e.g., “record electricity demands”; loss of electricity transmission, which cascades into transit stoppages; stranded commuters; and hot, poor air quality that could be exacerbated by heat-induced fires).

The following cities have identified rising temperatures as a potential risk and are in various stages of preparation and adaptation to cope with increasing temperatures (as outlined in the table below).

Stage Zero cities have populations at risk from rising temperatures and have not begun preparing for this risk. While the North African cities of Tunis, Casablanca, and Alexandria do have climate-adaptation plans, their focus is largely on other threats. For example, Alexandria is the only one of these cities to have a concrete recommendation for temperature adaptation; however, this is simply an education and awareness initiative.

9 Data from http://www.emdat.be/disaster_list/index.html

Table 2. Mediterranean Cities' Temperature Adaptation Stages

Adaptation stage	Region/City
Totals	23 out of 36 plans
Stage 0: Training	Algiers and Cairo
Stage 1: Assessment	Almada, Ancona, Gibraltar, Madrid, and Zadar
Stage 2: Recommendations	Cities: Alexandria, Barcelona, Cape Town, Lyon, San Diego, and Santiago Regions: Catalan, Israel, and Western Cape (South Africa)
Stage 3: Implementation	Cities: Adelaide, Belmont, Los Angeles(Airports and City), Melbourne, and South Perth Regions: California and South Australia

We divide these initiatives into aforementioned categories: (i) infrastructure and hard planning (i.e., zoning or strong building requirements) and (ii) persuasion and information strategies. Table S-2 (in supplementary materials) further details the specific types of actions cities are taking. Interestingly, the already-hot North African cities have climate-adaptation documents that do not contain specific strategies for adapting to increased temperatures.[10] Also, while there are many cities at the implementation stage, they are largely confined to California and Australia (with the exception of Lyon, France). Stage Two cities are slightly more geographically heterogeneous but still limited in number.

Stages Two and Three cities tend to have similar strategies for dealing with rising temperatures. The single most represented strategy is the reduction of the urban "heat island" effect by redesigning urban spaces and green infrastructures (e.g., via more trees and different landscaping and surface materials). Thirteen out of the sixteen cities with temperature components to their plans include infrastructure plans to reduce urban heat islands (Table S-2 has the details.) Furthermore, we find that regulatory measures are complementing infrastructure-planning efforts (to reduce urban heat islands). These regulatory measures include additional vector control regulations and enforcement, changing building codes, and requiring retrofits of existing buildings (to improve thermal comfort). Stage Three cities are particularly active in planning measures. In sum, heat-island reduction is a prime focus for many cities, a promising area for future cooperation, and is especially important to Mediterranean cities because many (i) are already hot in the summer, (ii) rely on tourism, and (iii) often prioritize quality-of-life issues. The following textbox shows how Adelaide is relying on regional cooperation and joint research with research institutions to plan for and mitigate urban heat islands.

10 There is a vague mention of heat waves and green space in Alexandria but nothing approaching an implementation plan.

Responses to Increased Temperatures in Adelaide

In Adelaide, the potential increase in extreme heat days due to climate change poses a significant risk to human comfort and contributes to rising cooling costs. In the city's 2013-2015 Climate Change Adaptation Action Plan they propose ongoing design initiatives aimed at reducing the urban heat island effect.

In particular, the suggested actions to be taken by City Planning and Sustainable City / City Design are: 1) Partnering with appropriate agencies to investigate the urban heat island effect and adopt solutions to mitigate its impact in the city; 2) Integrating landscaping (vegetation and water storage), and other measures into relevant asset renewals and strategic enhancements; and 3) Providing educational materials and strengthening provisions for green roofs and green walls in the city's Development Plan.

In the 2013-2015 Climate Change Adaptation Action Plan, they note that they have ensured resource efficiency and thermal comfort through advocacy aimed at State Government for improved incorporation of resource efficiency measures in the Development Plan and broader State policy (e.g., the Water Smart Urban Design guidelines). They also state that they have taken steps to reduce the urban heat island effect by participating in research partnerships to improve understanding and solutions of climate change with Flinders University and Cooperative Research Centres for Low Carbon Living. (References in Appendix A).

Persuasion strategies (i) are a key part of planning for most of the cities that have temperature-related plans; (ii) usually alert populations to heat-related dangers; and (iii) focus attention on cool spaces (via infrastructure, persuasion, and awareness to move vulnerable populations to cooling shelters). Table S-2 shows the large number of Stages Two and Three cities implementing persuasion. Persuasion strategies are largely aimed at educating the public – particularly vulnerable populations – about the dangers of high temperatures and how they can respond effectively.

The large proportion of cities working on measures to reduce urban heat island effects and then reduce the damage by educating the population on heat waves indicates both the importance of this climate danger and the potential large benefits of information-sharing across Mediterranean cities in this area.

Wildfires

Cold wet winters and dry hot summers are commonplace in Mediterranean climates; thus, these regions are typically vulnerable to seasonal fires during the summer. This makes wildfire adaptation a much greater priority in Mediterranean (vs. other) climate zones. Some work has indicated that this risk is likely to increase with climate change due to higher temperatures, reduced water supply, and prolonged drought (Matteucci et al., 2013).

Wildfires can have severe socioeconomic and ecological impacts and reduce biodiversity. Specifically, fire-generated air pollution (i) is a major threat to human health (Liu et al., 2015), (ii) can be detrimental to fauna and flora (and favor the spread of alien vegetation [Pausas et al., 2009]), and (iii) can lead to soil erosion (Pausas et al., 2009) that can, in turn, result in a (a) loss of topsoil, (b) silting of freshwater systems, which (c) further affects the environment. Furthermore, fires can be damaging to forestry and agriculture and threaten homes (notably those on the urban fringe).

Table 3. Mediterranean Cities Wildfire Adaptation Stages

Adaptation Stage	Region/City
Total	16 out of 36 plans
Stage 0: Training	None
Stage 1: Assessment	Almada, Andalusia, and Catalonia,
Stage 2: Recommendations	Cities: Cape Town, Cyprus, San Diego, and Los Angeles Regions: Israel and South Australia
Stage 3: Implementation	Cities: Adelaide, Belmont, Melbourne, and Perth Regions: California, Succulent Karoo, and Western Cape

Only about one-third of our locations included fire adaptation plans. Responses to the growing number of fires worldwide generally reflect pre-existing firefighting strategies (see supplementary Table S-3 for detail). About half of Stage Three cities are pursuing natural infrastructure-type strategies such as reducing fuels and constructing fire breaks. All but one Stage Three city is implementing persuasion strategies, such as emergency information systems and fire education. Stage Two cities are similar in their efforts, but have a somewhat broader set of plans. For example, Cape Town is planning to make a serious effort, as part of its climate-adaptation plan, to alter ecosystems to reduce fire risk and propensity (see the following textbox for a detailed description of Cape Town's fire-related planning).

We find no direct regulations associated with homebuilding in fire-prone areas, which contrasts sharply with the growing severity of wildfire dangers–particularly to homes in the high-risk wildland-urban interface (Theobald and Romme, 2007). Over this past decade, wildfires in Australia, California, and the Mediterranean have shown the heightened risks in wildland-urban interface (WUIs); for example, fire-prone areas (e.g., Oakland Hills near Berkeley, California) often re-burn and tend to follow a pattern experienced in regions affected by flooding. Thus, policymakers can somewhat predict areas that are prone to fire dangers. Interestingly, during our review, we found that two cities are at least considering retreats from flood-prone areas; however, no cities mentioned retreats from fire-prone areas and we do not find mention of insurance-based persuasion solutions to limit building in fire-prone areas (or enforcement of more stringent building requirements).

Because our review only examines climate documents, it may have missed wildfire planning outside of adaptation plans. However, there would be intrinsic weaknesses in wildfire plans if they are not synchronized with climate-adaptation planning. For example, the enactment of effective wildfire-adaptation policy is dependent upon complex climate analysis, associated data, and knowledge of overlapping strategies (e.g., power-grid adaptation measures.) Thus, while some current policies may be sufficient, it seems likely that many cities in our sample have not considered how fire policies should evolve in a new climate.

Our review indicates that there is a substantial group of cities that could share lessons on infrastructure and persuasion measures to ameliorate the increased wildfire risk from climate change.

Fire Risk Adaptation in the Western Cape

As a result of climate change, a potential increased number of bush fires with heightened intensity could threaten infrastructure throughout the Western Cape region of South Africa. Examples of at-risk infrastructure include energy transmission lines, water supply resources, and buildings. In response, A Climate Change Strategy and Action Plan for the Western Cape provides an analysis of adaptation strategies for the entire region as well as for the sub-regions: South West, North-West, South Coast, and Karoo.

Increasing provincial fire risk ratings is one of the primary measures proposed for safeguarding the region against climate change-induced wildfires. The plan cites this strategy as an important way to link land stewardship, livelihoods, and the economy. It is also a way to address other adaptation challenges, including effectively managing ecosystems and biodiversity.

A second strategy detailed in the plan is a wildfire education and awareness campaign targeted at marginalized communities. In particular, the planning document suggests that the region raise awareness in a way that translates into economic activity. This could mean, for example, offering trainings around fire prevention.

Another strategy that the region has implemented is rapidly deploying aerial support within the first hour of a fire ignition. The Western Cape Climate Change Response Strategy Biennial Monitoring & Evaluation Report states that this tactic has led to a success ratio of 97% of fire control within the first hour. The report also notes that this is helping to bolster the regional economy and natural resource base. Moreover, the strategy is an example of the, "outstanding intergovernmental and multi-stakeholder collaboration required for managing climate change." (References in Appendix A).

Water Cycle Changes

Climate change is likely to be currently affecting many aspects of the water cycle (e.g., extreme precipitation, drought, and evapotranspiration (ET) (Field et al., 2012) Of course, Mediterranean areas particularly are likely to be vulnerable to drought and flooding (Palutikoff et al., 2007). Most cities and regions acknowledge that water impacts are the most important climate-change impacts. However, water-cycle changes (vs. SLR) have more short-term variability and consequently are more difficult to predict and incorporate into planning. For example, variability in rainfall can lead to droughts on one hand or flooding on the other.

Flooding

Climate change is highly likely to result in a growing number of extreme precipitation events; furthermore, there is strong evidence that this is already occurring (Noble et al., 2014). Heavy rainfall events pose a high risk of flooding in certain areas (e.g., in regions where water tables are high, alongside rivers or natural water bodies, or in low-lying areas with poor drainage). Flooding can also occur in coastal cities and regions due to storm surges during extreme weather events, which could be exacerbated via SLR. Flood-prone cities already engage in planning and investments to reduce flood damage; thus, in some ways, climate adaptation for flooding is similar but more extensive than existing efforts. However, SLR and flooding, along with large increases in extreme precipitation events, are likely to result in threats of an entirely different magnitude. Cities like Norfolk, Virginia and Miami, Florida (Montgomery, 2014), have experienced the synergistic effects of SLR and flooding (e.g., higher sea levels can result in severe flooding with even typical rain events). Severe precipitation events, in the future, are likely to not only increase the damage but may also necessitate a qualitatively different approach to planning (vs. traditional flood-control approaches). This section will delve into how Mediterranean cities are currently approaching flooding adaptations.

Flooding poses many of the same risks as SLR for similar reasons (e.g., key infrastructure is often located in flood-prone zones and near sea level). Some of the problems and risks associated with flooding include:

- Storm-water management
- Impact on essential services (e.g., water and electricity)
- Dispersal of contaminants from hazardous waste sites
- Wastewater management
- Watercourse damage
- Rockfalls and landslides
- Potable water
- Damage to transportation routes (e.g., rails and roads)

This should be a familiar list, as many of these items appear on the list of SLR dangers. Flooding and SLR both affect the same kinds of infrastructure.

The following cities have identified flooding as a potential risk. These cities are in various stages of preparation and adaptation to cope with flooding (as outlined in the table below).

Table 4. Mediterranean Cities' Flooding Adaptation Stages

Adaptation Stage	Region/City
Total	26 out of 36 plans
Stage 0: Training	Cairo and Algiers
Stage 1: Assessment	Zadar, Ancona, Cyprus, Gibraltar, Palestine, and Almada
Stage 2: Recommendations	Cities: Alexandria, Cape Town, Casablanca, Los Angeles Metro, San Diego, Santiago, South Perth, Tel Aviv, and Tunis Regions: Israel and Succulent Karoo
Stage 3: Implementation	Cities: Adelaide, Belmont, Melbourne, Barcelona, and Los Angeles Airports Regions: Catalonia, South Australia Western Cape, and California

Similar to our sections on SLR and temperature, we have grouped together some of the most common actions that cities are planning (or pursuing) to adapt to flooding dangers (See Supplementary Table S-4 for a longer list of actions). Stage Three and Stage Two cities have similar flood adaptation strategies so we do not separate them out in this discussion. Infrastructure plans are heavily emphasized, with 17 of 18 cities represented in this section containing infrastructure plans. The wide-ranging plans include both green and gray solutions, enhancement of infiltration and rainwater harvesting in urban areas, and plans to rehabilitate or conserve natural waterways in order to increase flood protection. Different types of infiltration, diversion and rainwater harvesting appear to be the most popular adaptation mechanisms; nine of the 18 cities in this section are planning or implementing these solutions. This is a likely focus of future research since the effectiveness of different approaches to these problems can inform future efforts. Our detailed look at Catalonia's use of large stormwater system tanks (see textbox) demonstrates one variant of this strategy.

Anti-flooding Strategies at Work in the Catalonia Region

Anti-discharge of the unitary system tanks (anti-DSUs), also known as anti-flooding system tanks, are one example of an adaptation measure being employed to combat the effects of flooding on critical infrastructure in Catalan cities. In particular, anti-DSUs have been built in the Barcelona Metropolitan Area.

Beginning in 1997, the Barcelona City Council and CLBASA (a public-private partnership between the City Council and nongovernmental entities) built a series of anti-DSUs with 18 gates that are remotely controlled. The primary purpose of the anti-DSUs in Barcelona is to reduce the risk of flooding, which is likely to become more severe as the climate changes. Other reasons for using the anti-DSUs include guaranteeing a standard of potable water that is suitable for activities like bathing and improving the efficiency of the flow of water into treatment plants. In addition to being a critical climate change adaptation measure, the anti-DSUs are the main infrastructure in Barcelona to drain off rainwater, regulate flow, and reduce the risk of flooding associated with torrential rainfall. As of 2011, according to the Plan Integral de Clavegueram de Barcelona (PICBA 2006), Barcelona had built several anti-DSUs and was planning to build more. (References in Appendix A.)

Cities are also looking at ways to decrease their vulnerabilities to flooding by providing (i) safe evacuation centers, (ii) plans for (a) emergency vehicles (to use tracks to avoid flooded streets) and (b) alternative transportation, and (iii) installations of pumps in low-lying infrastructure (e.g., subways). Several cities also recognize that greater flood risks mean they have to develop greater capacities for emergency management (see also World Bank, 2011). This is an area where temperature, SLR, and flooding risks all demand superior emergency management infrastructures and capabilities (vs. what currently exists).

In contrast, (i) regulatory/zoning solutions and (ii) persuasion and information have received little emphasis in these adaptation documents with only two cities describing work in this area. This sharply contrasts with SLR-associated planning as many cities are now considering measures to restrict developments near vulnerable coasts and are also planning (or implementing) information or incentives to persuade property owners to (i) move out of vulnerable areas or (ii) reduce their property-related vulnerabilities. Some persuasion policy is likely implemented in the upgraded emergency response planning, but the main effort we could detect in emergency planning was in equipment and training.

This section shows that cities are experimenting with many different strategies to infiltrate stormwater in order to diminish flooding danger. We also see a number of cities planning flood adaptation for transportation infrastructure. These are both areas where future collaboration and lessons learned research should prove useful.

Reduced Water Supply & Drought

The unprecedented and ongoing drought and heat in California (Griffin & Anchukaitis, 2014) are illustrating some of the impacts of climate-change induced drought and subsequent threats to water supplies. Reduced water supply and drought can have knock-on effects, including:

- putting the water security of populations at risk due to limited water supply and/or deterioration in water quality (as pollutants become more concentrated when water flow drops);
- affecting the ability of farmers to irrigate their crops;
- promoting desertification (which can affect land use) and wildfire risks; and
- increasing social conflict over water.

Furthermore, the increased risk of wildfires provides an additional example of the synergies of climate impacts. For example, regions with Mediterranean climates experience cold, wet winters and dry, hot summers, which are often characterized by periods of drought followed by periods of torrential rainfall. Consequently, many of these regions are particularly vulnerable to a further reduced water supply and prolonged drought. Like wildfire, this is a threat that is more relevant to cities in semiarid and arid regions.

The following cities have identified reduced water supply as a potential risk. These cities are in various stages of preparation and adaptation to cope with drought (as outlined in the table below).

Table 5. Mediterranean Cities Drought and Water Supply Adaptation Stages

Adaptation Stage	Region/City
Total	25 out of 36 plans
Stage 0: Training	Cairo and Algiers
Stage 1: Assessment	Zadar and Ancona
Stage 2: Recommendations	Cities: Alexandria, Ankara, Cape Town, Hermanus/Overstrand, Los Angeles Metro, Madrid, San Diego, and Tel Aviv Regions: Catalonia, Israel, Palestine, South Australia, and Succulent Karoo
Stage 3: Implementation	Cities: Adelaide, Barcelona, Belmont, Los Angeles, Melbourne, and Perth Regions: California, and Western Cape

This is our best-represented area, with 70% of our sample plans containing drought-related adaptation sections. Stages 2 and 3 cities are quite similar in their planning so we will present them together.

Cities are planning and implementing a broad array of infrastructure upgrades to develop new water supply. Altogether, 15 of the 17 cities that have drought-related infrastructure plans for expanded water supply infrastructure. Many cities plan to expand conventional water sources (e.g., reservoirs and aquifers); others are planning for new types of water supply (e.g., storm water, recycled wastewater, and/or desalination). Our review indicates that (i) increased water supply is the priority for most cities (see Table S-5 for the number and variety of supply expansions detailed in the reports) and (ii) most of the focus is on traditional, grey infrastructure. However, there is some green infrastructure (e.g., the green elements of storm-water capture and the removal of thirsty non-native vegetation). Melbourne (see the detailed description in the following textbox) is one example of a city that is putting heavy emphasis on infiltration strategies to increase water supply. However, water supply planning is integral to urban planning, so it is difficult to know how many of these actions are new and how many are simply being repackaged (e.g., the Tel Aviv water sustainability plan is not solely or mainly a climate-change adaptation document but climate adaptation is part of the planning for Tel Aviv's upgraded water infrastructure).

Municipal Water Supply and Drought Strategies: Melbourne's Water Smart Urban Design Guidelines

In 2006, Melbourne released a comprehensive set of Water Smart Urban Design (WSUD) Guidelines. The primary purposes of the guidelines is to present measures that will minimize and/or avoid the environmental impacts of urbanization, particularly on water demand and pollution in natural water bodies, and to simultaneously increase the city's capacity to cope with climate change impacts on water supply and drought. The intended audience for the document includes Melbourne's local government staff, developers, and residents.

In 2011, Melbourne developed a second round of WSUD Guidelines specifically for southern and eastern Melbourne. The second guide includes targets and objectives, processes and approvals for the various phases for WSUD projects. The document also provides the City Council with specific information that should be considered for WSUD projects within each part of the city. By assembling a manual targeted at subsections of Melbourne, the document supports local action as a means for implementing adaptation measures.

Bioretention basins, also known as rain gardens, are one example of an implemented adaptation strategy that is outlined in the WSUD Guidelines for southern and eastern Melbourne. Other green infrastructure options outlined in the guide include: vegetated swales, sand filters, sedimentation basins, constructed wetlands, pools/shallow lake systems, and rainwater tanks. (References in Appendix A).

The *direct regulation* and *persuasion and information* sections of Table S-5 reveal an emphasis on the demand side of the water equation. Twelve areas are considering (or implementing) direct, regulation-style water-use restrictions. In addition, tiered water pricing structures and water-conservation campaigns are often mentioned in the documents as options for persuading people to reduce water demand. Many cities demonstrate a focus on decreasing outdoor irrigation and increased information about water quality. Interestingly, Adelaide has plans to maintain the quality of sporting facilities in the face of drought and heat; however, this quality-of-life emphasis is (i) missing in most of the other cities and (ii) important and interesting for other areas to consider because tourism is a key part of the economy for most Mediterranean cities.[11]

This paper focuses on urban climate adaptations. However, nearby agriculture can be important for urban areas for a number of reasons (e.g., food security and economic and cultural considerations). For this reason, Israel, Palestine, and Catalonia include a series of agricultural adaptations in their plans. Some of this planning is quite similar to urban adaptations (e.g., improved irrigation efficiency and better information about water supply); however, other considerations are agriculture-specific (e.g., switching crop varieties and feed inputs).

This section shows the large number of cities working on stormwater capture plans both for flood control and water supply. The Mediterranean climate, with its infrequent but heavy rainfall, poses unique challenges for designing stormwater capture, especially when designing for the two different objectives of water supply and flood reduction. The other types of unconventional water source infrastructure are likely to offer different challenges in Mediterranean climates than in other areas because of ecosystem impacts, for example the additional salts in recycled wastewater may be more difficult to handle in areas with infrequent rainfall.

Energy, Greenhouse Gas Emissions, and Air Pollution

Air quality in urban areas is predicted to deteriorate due to heat-induced increases in concentrations of atmospheric pollutants (e.g., ozone and particulate matter). Increased air pollution can (i) worsen respiratory conditions and allergies, (ii) increase mortality(Jacob and Winner, 2009), and (iii) have significant economic costs(West et al., 2013). Local air pollutants are co-emitted with greenhouse gas emissions (GHGs) during fossil fuel combustion; consequently, the reduction of GHGs can be viewed as both a climate-mitigation and a climate-adaptation measure (West et al., 2013).

Energy production is a related concern. We are accustomed to thinking of the energy sector as the generator of GHG pollution. However, climate change also complicates energy production (e.g., it is likely to reduce the efficiency of thermoelectric energy production (Houser et al., 2015). Energy planning will need to take into account (i) the reduction in efficiency and (ii) increased marginal damage of pollutants due to climate change. In other words, if cities and regions commission more fossil fuel plants to cope with efficiency losses, they need to account for how those pollutants will affect public health.

11 Euromonitor 2016 reports a ranking of top 100 cities for tourism; Mediterranean cities such as Istanbul (10), Rome (4), Milan (24), Barcelona (26), and Los Angeles (29).

Table 6. Mediterranean Cities' Energy and GHGs Adaptation Stages

Adaptation Stage	Region/City
Total	15 out of 36 plans.
Stage 0: Training	Cairo and Algiers
Stage 1: Assessment	Almada
Stage 2: Recommendations	Cities: Los Angeles (Metro), Madrid, San Diego and Santiago Regions: Israel
Stage 3: Implementation	Cities: Adelaide, Belmont, Los Angeles – Airports, Lyon, and Perth Regions: South Australia, and Western Cape

Somewhat less than half of our cities have Energy and GHG plans, but these areas have detailed plans. Not surprisingly, many of the measures that have advanced to implementation have significant synergies with GHG reduction (where efforts started earlier). Stages Two and Three cities are not notably different in their efforts in this area.

The most widespread of infrastructure measures for Stages Two and Three cities is long-term energy planning for climate change (which is also a major part of GHG reduction). (See Table S-6 for details.) Nine of the twelve Stage Two and Stage Three cities have plans in this area. Dual mitigation and adaptation measures to improve air quality (e.g., public transport, improved building energy-efficiency, and alternative fuels) are also present in many Stages Two and Three cities. Lyon (see textbox at the end of this section for the detailed description) is an example of integrated transportation and planning for both mitigation and adaptation purposes. There are many other dual mitigation and adaptation measures mentioned as well (e.g., urban planning to lower energy use and efficient waste management). Finally, some cities are planning to upgrade (i) their air-quality monitoring infrastructure and (ii) complementary regulatory measures to reduce local air pollutant emissions and limit traffic.

All of the Stage Two and Stage Three cities have persuasion polices, and they are largely aimed at reducing driving and increasing driving of vehicles that use alternative fuels. Also, cities are active in improving building energy efficiency, some cities through measures such as building codes and voluntary standards (e.g., Leadership in Energy and Environmental Design).

Many cities are at the implementation stage in the management of air quality, energy, and GHG emissions; thus, an in-depth examination of outcomes is a promising area for future research. In particular, the energy system alterations necessary to adapt to the particular climate changes in the Mediterranean climate zone, such as extreme heat that leads to increased energy demand and the failure of some energy system components, may necessitate research that shares the lessons from cities facing these particular challenges.

Managing Energy, Greenhouse Gas Emissions, and Air Pollution in Lyon with the Territorial Cohesion Scheme

Lyon is employing a concentrated effort to reduce greenhouse gas emissions and air pollution using a territorial cohesion scheme (SCOT). In addition to greenhouse gas mitigation, the goals of this strategy are to make Lyon cleaner and to conserve its resources.

SCOT has three main components: 1) Improving public health and the environment by limiting motorized travel and promoting environmentally friendly means of transport; 2) Saving and diversifying resources by turning towards renewable sources of energy; and 3) Attempting to secure and diversify resources like drinking water and construction materials. The strategy targets a carbon-neutral Lyon by 2020.

One of the approaches that SCOT calls for is the promotion of transit-oriented locations for employment, housing, and other city services. For Lyon, this requires developing a strong public transportation network. Lyon has taken several steps to expand its existing system, such as investing in the extension of busy bus lines. Their 2015 Territorial Climate and Energy Plan Progress Report states that city-sponsored actions aligned with SCOT have led to a 24% increase in ridership on public transportation between 2006 and 2014. Lyon also has initiatives aimed at promoting cycling, which rose threefold between 2005 and 2015. This includes to Velo'v bikeshare system and the expansion of cycling infrastructure throughout the city such as two-way cycle tracks, 260 km of traffic calming zones, and 121 km of greenways. (References in Appendix A).

DISCUSSION

This review highlights many common adaptation themes across cities. Many cities are pursuing plans to decrease "heat island" effects via urban redesigns or green infrastructure. Another common theme is increasing the permeability of surfaces to decrease flooding and replenish aquifer. These plans date back several years. Therefore, there should soon be experience with these projects and, by comparing successes and failures, cities can plan midcourse corrections.

We also see some common gaps in the plans that we reviewed. Buildings and infrastructure have limited lifetimes; therefore, retreats that gradually cut down building in particularly dangerous areas are likely to be less costly (vs. the loss of relatively new buildings). However, there is very limited effort to retreat from areas prone to flooding and widespread fires. Based on our review, we (i) cannot discern whether these cities are making the correct decisions on retreat, and (ii) recommend this as an area for future discussions between city policymakers and stakeholders.

An overarching observation is that the adaptation plans of cities involve significant modifications or upgrades to every major piece of infrastructure. For instance, SLR and flooding responses include not only obvious upgrades to storm-water and sea protection infrastructures but also less obvious (but equally necessary) upgrades to wastewater, energy, and solid-waste facilities. Furthermore, flooding and drought responses include major changes to the land cover in cities to enhance permeability and water storage. Similarly, measures to adapt to a hotter climate and air-quality degradation will require a very different built environment. Transportation infrastructure measures include plans to (i) decrease vulnerability to flooding and (ii) increase mass-transit ridership to decrease pollution and GHG emissions. There are also plans to enhance government capacities associated with monitoring, information, and enforcement—across a number of areas.

We have noted several areas where Mediterranean climate cities have to jointly consider several climate challenges in their adaptation plans. However, the broad infrastructure restructuring discussed previously likely means that there are many other areas we have not identified where cities can learn lessons from other areas that are facing a similar set of challenges and upgrading a similar set of infrastructure.

The simultaneous upgrading of the built environment, infrastructure, and other public facilities, within cities, is a tremendous financial and governance challenge; for this reason, it is not surprising that Carmin et al.'s (2012) survey of city-adaptation planning found that cities' biggest adaptation challenges are resources and funding. We appreciate the magnitude of this challenge when we consider the difficulties of replacing 90-year-old water mains in Los Angeles. In July 2014, one water main broke, spilling 20 million gallons of water during an extreme drought; this caused over $30 million in damages. Upgrading a leaky, old, and disaster-prone water system is one of many challenges that cities (e.g., Los Angeles) must manage in order to adapt to climate change. (Interestingly, the current schedule in Los Angeles will only fully replace the nearly 100-year-old system in 300 years.) Challenges can include not only cost but also the public's trust in associated government agencies (Archibald, 2009). The governance and financing issues raised by these infrastructure overhauls, – though similar across all cities, not just Mediterranean ones – are also crucial topics of research and lesson-sharing. We hope this review of adaptation plans propels this necessary research and lesson-sharing forward.

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Appendix B. Table I

Name	Type of Area	Range of Issues
Adelaide	City	General
Alexandria	City	General
Almada	City	General
Algiers	City	General
Ankara	City	Drought Only
Athens	City	General Environmental Plan
Barcelona	City	(1) General Report and (2) Extreme Rainfall
Belmont	City	General
California	Region/Country	General
Cairo	City	General
Capetown	City	(1) General Report and (2) Sea Level Rise
Casablanca	City	General
Catalonia	Region/Country	General
Cyprus	City	General
Gibraltar	City	General
Hermanus/Overstand	Region/Country	General
Israel	Region/Country	General
Ancona. Italy	City	General
Karoo	Region/Country	General
Los Angeles City	City	General
Los Angeles Airports	City	Airports Only
Los Angeles Metro	City	Public Transportation Only
Lyon	City	General
Madrid	City	Energy Climate Change with Adaptation
Melbourne	City	General
Palestine	Region/Country	General
San Diego	City	(1) General Report and (2) Sea Level Rise
Santiago	Metropolitan Area	General
South Australia	Region/Country	General
South Perth	City	General
Andalucia	Region/Country	Drought and Fire Only
Tel Aviv	City	Water Only
Tunis	City	General
West Cape, SA	Region/Country	General
Zadar	City	General