Accepted: 2 February 2018

DOI: 10.1002/geo2.52

RESEARCH ARTICLE

Opportunities for biodiversity conservation as cities adapt to climate change

Nathalie Butt[1] | **Danielle F. Shanahan**[1,2] | **Nicole Shumway**[1,3] | **Sarah A. Bekessy**[1,4,5] | **Richard A. Fuller**[1] | **James E. M. Watson**[3,6] | **Ramona Maggini**[1,7] | **David G. Hole**[8,9]

[1]ARC Centre of Excellence for Environmental Decisions, School of Biological Sciences, The University of Queensland, St Lucia, Qld, Australia

[2]Zealandia Sanctuary, Karori, Wellington, New Zealand

[3]School of Earth and Environmental Sciences, The University of Queensland, Brisbane, Qld, Australia

[4]Centre for Urban Research, RMIT University, Melbourne, Vic., Australia

[5]National Environment Research Programme, Clean Air and Urban Landscapes Hub, RMIT University, Melbourne, Vic., Australia

[6]Wildlife Conservation Society, Global Conservation Program, Bronx, NY, USA

[7]School of Earth, Environmental and Biological Sciences, Queensland University of Technology (QUT), Brisbane, Qld, Australia

[8]Betty and Gordon Moore Centre for Science and Oceans, Conservation International, Arlington, VA, USA

[9]School of Biological and Biomedical Sciences, University of Durham, Durham, UK

Correspondence
Nathalie Butt
Email: n.butt@uq.edu.au

Funding information
Australian Research Council (ARC) Future Fellowship, Grant/Award Number: DE150101552; ARC Discovery Grant, Grant/Award Number: DP120102857

Cities are investing billions of dollars in climate change adaptation to combat the effects of sea-level rise, temperature extremes, increasingly intense storm events, flooding and water scarcity. Natural ecosystems have enormous potential to contribute to city resilience, and so, actions that rely on this approach could sustain considerable co-benefits for biodiversity. In this paper we identify the prevalence of key themes of human adaptation response that could have biodiversity conservation outcomes in cities. We then quantify the area of impact for actions that identify specific targets for greening or green infrastructure that could involve natural ecosystems, providing an indicator of potential co-benefits to biodiversity. We then extrapolate to explore the total area of land that could benefit from catchment management approaches, the area of waterways that could benefit from nature-based improvement of these spaces, and finally the number of threatened species that could benefit across these cities. From 80 city climate adaptation plans analysed, we found that urban greening plays a key role in most adaptation strategies, and represents an enormous opportunity for biodiversity conservation, given the diversity of animal and plant species in urban environments. We show that the ranges of at least 270 threatened species overlap with the area covered by just 58 city adaptation plans, including watershed catchments totalling over 28 million km^2. However, an analysis of 80 city adaptation plans (of a total 151 found globally) shows that this opportunity is being missed. Just 18% of the plans assessed contained specific intentions to promote biodiversity. We highlight this missed opportunity, as climate adaptation actions undertaken by cities represent an enormous incipient opportunity for nature conservation. Finally, we encourage planners and city governments to incorporate biological conservation into climate adaption plans, for the mutual benefit of urban societies and their biodiversity.

KEYWORDS
biodiversity, climate change adaptation, conservation planning, urban environment, urban population

1 | INTRODUCTION

Cities are at the frontline of climate change impacts, and are leading the way in the implementation of adaptation actions (Broto & Bulkeley, 2013; Rosenzweig, Solecki, Hammer, & Mehrotra, 2010). These often involve large-scale environmental management, which can have negative (e.g., sea walls, vegetation clearance to insulate against wildfire) or positive implications for biodiversity (e.g., catchment afforestation, tree planting, more green space) (Solecki & Marcotullio, 2013). Biodiversity conservation could be jeopardised by, or benefit enormously from, such actions, and there is therefore an urgent opportunity to identify conflict and synergies between city climate adaptation and nature conservation.

Most cities are located on coasts or rivers, making them acutely vulnerable to impacts such as sea-level rise, storm surges and flooding (Rosenzweig et al., 2010; Rosenzweig, Solecki, Hammer, & Mehotra, 2011). Globally, 414 cities are now directly threatened by sea-level rise under current emissions trajectories, imperilling more than 400 million people (Strauss, Kulp, & Levermann, 2015). Climate change exacerbates the existing vulnerabilities of urban environments, which are generally drier and warmer than the surrounding landscape (Moriwaki, Watanabe, & Morimoto, 2013), and often lack protective or buffering vegetation. Impacts on urban environments are expected to have enormous ramifications for humanity, with over half of the world's population now living in cities and urban areas, projected to increase to two-thirds by 2050 (United Nations, 2014). Such large aggregations of people demand extensive and highly concentrated infrastructure, and because of this spatial concentration even localised climate change impacts can have potentially devastating and costly impacts on both economic and social systems (Hunt & Watkiss, 2011; McGranahan, Balk, & Anderson, 2007).

Cities contribute greatly to global-scale climate change, through high levels of greenhouse gas emissions, and drive more local-scale changes in temperature and precipitation regimes (Grimm et al., 2008; Kalnay & Cai, 2003). However, cities also have the economic power and resources to respond quickly and innovatively to threats (Rosenzweig et al., 2010), and since the turn of the century, following on from the Kyoto Protocol in 1997, and the creation of several international city-based alliances, they have become important players in climate change governance, arguably well ahead of nation states (Betsill & Bulkeley, 2007; Broto & Bulkeley, 2013).

There are several programmes and consortia that work towards the development and implementation of climate adaptation plans for cities, such as the Urban Climate Change Research Network (http://www.uccm.org/), the World Mayors Council on Climate Change (WMCCC), the C40 Cities Climate Leadership Group, the Asian Cities Climate Resilience Network, the UN Global Environment Facility (GEF) Sustainable Cities Program, and a range of published research articles concerned with the urban governance of climate change (e.g., Bulkeley, 2010; Hunt & Watkiss, 2011).

Levels of investment in climate change adaptation have increased dramatically in recent years, with New York City alone spending £1.6 billion in 2014/15 (Georgeson, Maslin, Poessinouw, & Howard, 2016). In cities across the world, 1.7 million adaptation actions are now underway (Cities & Group, 2014), with many harnessing ecosystem services both within cities and in the surrounding landscape to buffer the impacts of climate change. Many of these actions, such as catchment afforestation, street tree planting, and additional green space provision (Solecki & Marcotullio, 2013), will not only reduce human exposure to climate hazards (e.g., watershed forests can store runoff and reduce flood risk [Huang, Kang, & Li, 1999]); and increasing the density of urban trees can reduce ambient air temperatures (Bolund & Hunhammar, 1999), and increase resilience (e.g., maintaining freshwater provision through the conservation of bofedales/paramos; Martin & Watson, 2016), but also have the potential to provide considerable benefits for biodiversity conservation. This is especially important given that urbanisation embodies one of the most dramatic forms of land use transformation, often resulting in the permanent and wholesale replacement of natural habitat with built structures, adversely affecting biodiversity (McKinney, 2006; Seto, Fragkias, Guneralp, & Reilly, 2011).

While many factors influence the spatial location of cities, they often coincide with areas with high levels of native biodiversity (Balmford et al., 2001), and some contain important ecosystems and habitats for endangered species (Bekessy et al., 2012; Mason, 2000). For example, 22% of the known occurrences of endangered plants in the USA fall within the 40 largest cities (Schwartz, Jurjavcic, & O'Brien, 2002). Many cities contain globally threatened birds (Aronson et al., 2014), and Australian cities support disproportionately more nationally threatened species than non-urban areas (Ives et al., 2016). Cities and their associated peri-urban areas can therefore provide important opportunities for threatened species conservation, and climate change adaptation planning offers a unique opportunity to integrate proactive planning for biodiversity into urban landscapes. Currently, while climate change action plans address urban and societal climate change issues, there is almost no mention of, or accounting for, how biodiversity fits into, or will be affected by, the adaptation actions. In general, ecosystems are only considered in terms of being identified as vulnerable, or as important for the provision of ecosystem services for human health and wellbeing (Rosenzweig et al., 2011).

Some of the planned adaptation actions in and around cities are significant in scale and implementation, and may have a greater effect on urban biodiversity than the direct impacts of climate change (Hunt & Watkiss, 2011). Despite this, the opportunities and threats associated with these effects on biodiversity are poorly understood (Solecki & Marcotullio, 2013). For example, regeneration of vegetation carried out to improve the local climate of the urban environment could simultaneously provide increased habitat for woodland species (Gill, Handley, Ennos, & Pauleit, 2007), while protecting urban watersheds (extending action outside the bounds of the city itself) will promote ecosystem intactness, enhance freshwater habitats and help maintain species community composition. Thus, these actions could counter many of the negative effects of increasing urbanisation on biodiversity, including degradation and loss of habitats as cities sprawl or become more dense (Fuller & Gaston, 2009; McKinney, 2002).

Here we assess the extent to which 80 city climate adaptation plans identify the potential for co-benefits for biodiversity. We then quantify the scale of those potential benefits for catchments, freshwater systems and threatened species, and identify specific types of actions within these plans that could deliver co-benefits.

2 | MATERIALS AND METHODS

Cities with climate adaptation plans were identified online using Google and the search terms "city climate adaptation plan", "city climate action plan", and "city climate implementation plan", supplemented later by the city names. The initial search, carried out between October 2014 and 2015 (with some updating in 2017), identified 151 cities across 51 countries and six continents with some description of a climate change adaptation plan. Of these, 80 were readily available online and primarily in English, and were assessed in detail (Figure 1; Table 1). Although we were able to analyse more than half of all available city plans and in doing so achieved reasonable global representation, there was a clear geographical bias, with less representation from South American and African cities than for the other continents.

2.1 | Synthesis of climate adaptation plans

Following the typology laid out by Biagini, Bierbaum, Stults, Dobardzic, and McNeeley (2014), adaptation actions listed within the plans were grouped into ten categories: physical infrastructure; management and planning; green infrastructure; practice and behaviour; technology; policy; information; capacity building; warning or observing; financing. The actions

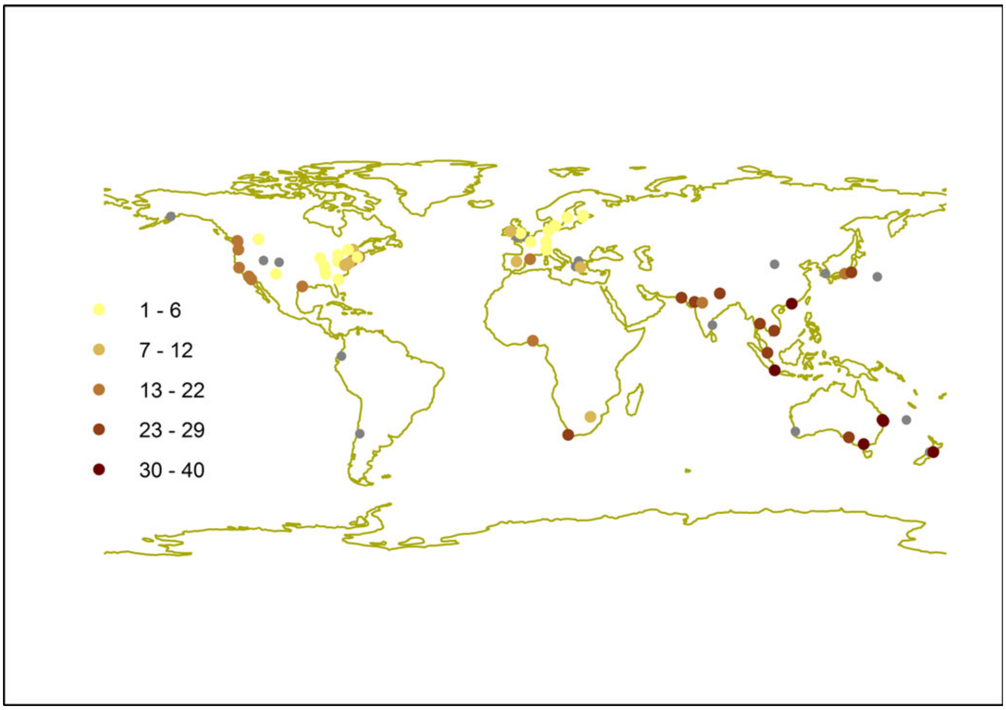

FIGURE 1 Eighty cities with adaptation plans assessed (all circles). While there is some inevitable spatial bias (due to the selection criteria), all urbanised continents are represented in the analysis. Increasing depth of colour (pale yellow–dark orange) represents the increasing number of threatened species per city (from 1–5 to 36–40: see key). Grey circles indicate no threatened species data available

TABLE 1 All city plans identified; the 80 readily available online and mainly in English are emphasised in bold

Addis Ababa, Ethiopia	Denver, USA	New Orleans, USA
Adelaide, Australia	Dhaka, Bangladesh	**New York, USA**
Ahmedabad, India	Dresden, Germany	Oslo, Norway
Alameda, USA	**Dublin, Ireland**	**Ottawa, Canada**
Albertirsa, Hungary	Durban, South Africa	**Oxford, UK**
Albuquerque, USA	**Evanston, USA**	**Paris, France**
Alexandria, USA	**Exeter, UK**	**Patras, Greece**
Amsterdam, The Netherlands	Freemantle, Australia	**Philadelphia, USA**
Ancona, Italy	Ghent, Belgium	**Pittsburgh, USA**
Antwerp, Belgium	Glasgow, UK	**Pomaz, Hungary**
Aspen, USA	**Gold Coast, Australia**	**Portland, USA**
Athens, Greece	**Gorakhpur, India**	Port Phillip, Australia
Auckland, New Zealand	**Hamburg, Germany**	Qui Nhon, Vietnam
Austin, USA	**Hamilton, USA**	**Quito, Ecuador**
Baltimore, USA	Hanoi, Vietnam	**Redland, Australia**
Bandar Lampung, Indonesia	Hat Yai, Thailand	Riga, Latvia
Bangkok, Thailand	Heidelberg, Germany	Rio de Janeiro, Brazil
Barcelona, Spain	**Helsinki, Finland**	Rome, Italy
Basel, Switzerland	**Ho Chi Minh City, Vietnam**	Rotterdam, The Netherlands
Beijing, China	**Hobsons Bay, Australia**	**Salt Lake City, USA**
Bellingham, USA	**Homer, USA**	**San Diego, USA**
Berkeley, USA	**Hong Kong, China**	**San Francisco, USA**
Berlin, Germany	**Houston, USA**	**Santiago, Chile**
Birmingham, UK	**Indore, India**	Sao Paulo, Brazil
Blacktown, Australia	Istanbul, Turkey	Seattle, USA
Bogota, Colombia	**Jakarta, Indonesia**	Semarang, Indonesia
Bologna, Italy	**Johannesburg, South Africa**	Seoul, South Korea
Boston, USA	**Kalamaria, Greece**	Sfantu Gheorghe, Romania
Boulder, USA	**Karachi, Pakistan**	Shanghai, China
Brighton-Hove, UK	**Keene, USA**	Shenzhen, China
Brisbane, Australia	**Lagos, Nigeria**	**Singapore, Singapore**
Buenos Aires, Argentina	Leicester, UK	**Stockholm, Sweden**
Bullas, Spain	Lima, Peru	**Stuttgart, Germany**
Cairo, Egypt	London, UK	Surat, India
Calgary, Canada	**Los Angeles, USA**	Sydney, Australia
Can Tho, Vietnam	**Louisville, USA**	**Tallinn, Estonia**
Cape Town, South Africa	**Madrid, Spain**	Tatabanya, Hungary
Caracas, Venezuela	**Malmo, Sweden**	**Tokyo, Japan**
Changwon, South Korea	Manchester, UK	Toronto, Canada
Charleston, USA	**Mandurah,** Australia	Tshwane, South Africa
Chattanooga, USA	**Melbourne,** Australia	**Vancouver, Canada**
Chennai, India	Mexico City, Mexico	Venice, Italy
Chiang Rai, Thailand	Miami, USA	Vienna, Austria
Chicago, USA	**Milan, Italy**	Warsaw, Poland

(Continues)

Copenhagen, Denmark	**Montreal, Canada**	**Washington, DC, USA**
Curitiba, Brazil	Moscow, Russia	**Wellington, New Zealand**
Danang, Vietnam	Mumbai, India	**Worcester, USA**
Dar es Salaam, Tanzania	Munich, Germany	Wuhan, China
Darebin, Australia	**Nagoya, Japan**	Yokohama, Japan
Darwin, Australia	Nairobi, Kenya	
Delhi, India	**Nelson, New Zealand**	

were reviewed by three ecologists and those associated with potential biodiversity benefits were identified alongside the specific climate impact that was being addressed. These were then allocated to one of four categories: "threatened species" (actions that make some effort to improve outcomes for threatened species), "catchment area" (actions that improve the environmental quality of watersheds), "greening" (where vegetation is increased or enhanced), and "water" (actions that improve the environmental quality of watersheds and rivers). For every action we also identified whether the plan stated it was designed to conserve or help promote nature, and whether it was designed to help people adapt.

2.2 | Quantifying potential biodiversity benefits

For each city we first recorded any actions classified as "greening" that provided a specific measure such as number of trees, or increase in percentage forest cover. We spatially estimated (in ArcGIS) the potential area of impact of these actions if possible (e.g., where a % area of improvement was identified) based on the World Urban Areas layer (available for 75% of selected cities; DeLorme, 2015).

Using the spatial analysis approaches described below, we then quantified the potential benefits to biodiversity if all cities in the spatially identifiable sample were to carry out actions involving "catchment area", "water" and "threatened species" (see Figure S1 for Methods plan).

We estimated the potential scale of these benefits using relevant GIS layers for each typology within ArcGIS overlaid with the World Urban Areas layer (DeLorme, 2015). The approach undertaken here is designed at a global scale to provide a broad indication of the potential biodiversity outcomes for sampled cities, rather than a specific indication of exactly what might be possible, taking into account limitations that might exist city by city. Furthermore, it must be noted that this analysis does not provide full global coverage of every city, rather it samples a range of cities that have accessible plans.

The methods for the spatial analyses were as follows:

Catchment area: We calculated the total area of the catchments within which the cities that mentioned catchment efforts as actions were located. This calculation was based on the USGS HydroSHEDS world Drainage Basins layer (15 s; USGS, 2013).

Water: We calculated the total area of rivers within city limits based on the River Network (15 s; USGS, 2013).

Threatened species: We calculated the total number of threatened or near threatened species (i.e., species listed under the IUCN Red List as critically endangered, endangered or near threatened) for which the geographic distribution, estimated by Birdlife International and Nature Serve (2014), overlapped with the cities of interest (and as such could benefit from habitat restoration or enhancement). The focal groups included species on the IUCN Red List: mammals, reptiles, amphibians, fresh water fish (IUCN, 2015), and birds (Birdlife International & NatureServe, 2014).

3 | RESULTS AND DISCUSSION

"Physical infrastructure" and "Green infrastructure" were the most common types of action across the city adaptation plans reviewed (Figure 2). "Green infrastructure" is typically used to refer only to built elements, such as green walls or green roofs (Biagini et al., 2014), but we also included urban greening in this category, which refers to planting trees or other vegetation in the wider urban environment. Urban greening was a commonly listed action, with some mention of vegetation planting or protection of natural areas in 72% of plans (Figure 2). Biodiversity was mentioned in 51 of the 80 plans, but actually explicitly discussed in terms of promotion and co-benefits from adaptation actions in only 14 plans (18%). Monitoring and surveying of various biodiversity attributes, from butterfly populations to water quality, appeared in 24 plans (30%).

The cities for which we extracted spatial data (58) are situated within a total catchment area of over 28 million km^2. Thus, catchment protection actions that contribute to provision or enhancement of habitats within these areas could amount to considerable biodiversity gain. Several city plans focus on watershed protection and water retention. For example, Ho Chi Minh City (Vietnam) plans include reservoir management, the development of a ring dyke, and protection of the riparian zone, with flood prevention as a key aim. Protection of the riparian zone (e.g., Lagos, Nigeria) offers potential benefits for biodiversity in terms of maintaining habitat intactness and species composition. River pollution is also targeted for reduction in the Ho Chi Minh City plan, providing further opportunity for biodiversity benefits.

The geographic distributions of 271 threatened species overlap the areas covered by the city climate change adaptation plans analysed. This includes 17 amphibians, 66 mammals, 38 reptiles, and 150 birds, with species designated as critically endangered, endangered or vulnerable. Many more species beyond those that are threatened are also likely to benefit from city adaptation actions. Some cities, such as Copenhagen (Denmark) and Rotterdam (The Netherlands), for example, have plans that include the creation of dispersal corridors for plants and animals. Where tree planting for city greening is part of the city plan, several cities highlighted the importance of using native species and species tolerant of future climate conditions, as well as those more resistant to invasion and pathogens.

3.1 | Watershed protection

Watershed protection activities could contribute significantly to biodiversity by reducing polluted runoff, and by improving water flow within these areas. This could amount to significant improvements for a total river length of 5,872 km, and

FIGURE 2 Examples of city climate adaptation action themes. The size of the circle is proportional to the number of actions listed in the 80 city plans analysed, for each of the ten categories, from largest to smallest: physical infrastructure (73 actions); management and planning (62); green infrastructure (57); practice and behaviour (55); technology (52); policy (49); information (45); capacity building (40); warning or observing (22); financing (20)

possible occurrence of 91 threatened fresh water fish species within the identified cities. Given that cities are already drier and warmer than the surrounding landscape (Moriwaki et al., 2013), and urban water demand is high (60% of urban water use is in cities; Grimm et al., 2008), water management is a focus of many city adaptation plans (e.g., Copenhagen, Rotterdam, Lagos). Water storage can be boosted through the development of underground storage for rainwater, and by increasing the capacity of ditches, canals, waterways and lakes. The replenishment of water supplies is an important aim for cities already dealing with problems caused by water shortages or fluctuations in availability. Fostering the use of rainwater is another way of relieving pressure on urban water supplies.

Extreme weather events such as storms can lead to large amounts of water in a short space of time, which can be damaging to infrastructure and dangerous for a city's inhabitants. "Cloudburst management", whereby sudden extreme amounts of storm water influx can be buffered at the same time as rain water is captured and stored, has the potential to provide improved habitat for biodiversity as related actions can include planting flood-tolerant tree species for storm buffering, increasing sluicing through the construction of rain gardens, and planting linear infiltrating vegetation in street gardens and public areas. In addition, cloudburst management could improve water flow in riverine ecosystems through the use of porous paving, also potentially reducing runoff, and storm barriers and dykes could contribute to reduced pollution in waterways by preventing water influxes into cities.

3.2 | Vegetation cover increase

Tree planting, increasing canopy cover and restoring native vegetation were widely listed (82% [66 plans] of cities mentioned greening), and may contribute in a range of ways to biodiversity conservation, both within the city and in catchments where tree planting is also planned. Benefits for biodiversity include improved habitat quality and reduced fragmentation (Barrett et al., 2008; Shanahan, Miller, Possingham, & Fuller, 2011). The development and installation of green roofs, or green walls, and green infrastructure are frequently cited in city adaptation plans, and may involve rooftop gardens, street trees, communal vegetable gardens, and replacing paving with planting (e.g., Copenhagen). In many cases, the design of these greening initiatives also incorporates efficient water use, and water capture and storage. Neighbourhood

TABLE 2 Actions from selected city climate adaptation plans that focus on "greening" through tree planting and increasing cover. The climate impact addressed, and the overall aim (design) of the adaptation action, varies by city. Targets for tree cover are commonly around 40%, and the numbers of planted trees range from thousands to millions

City	Action	Climate impact addressed	Quantification of impact – increase in city tree cover, km^2 (% of city area)	Designed to conserve/ help nature	Designed to help people adapt
Alexandria	Tree planting, acquisition of additional park space	Urban heat island impacts, watershed protection, wildlife habitat protection	265 (40)	Yes	Yes
Baltimore	Tree planting, policy to protect existing trees	Urban heat island effect, urban forestry offers bird habitat, improves air quality, and absorbs greenhouse gas emissions, helping to reduce climate change, waterway management	413 (40)	Yes	Yes
Boston	Tree planting	Heat Island effect, flood mitigation, air quality	38 (35)	No	Yes
Charleston	Tree planting	Heat island effect reduction, carbon sequestration, and runoff retention	13 (40)	No	Yes
Chattanooga	Tree planting in parks	Greenhouse gas sequestration	146 (40)	Yes	Yes
Nagoya	Tree planting	–	131 (40)	Yes	No
Ottawa	Tree planting	Carbon sequestration, removal of air pollutants, reduce heat effects, storm water drainage	118 (30)	No	Yes
Portland	Tree planting	Sequestering carbon dioxide, by reducing building energy use through cooling and shading in summer and lessening heat loss in winter	92 (30)	Yes	Yes

parks can provide water storage during periods of heavy rainfall (e.g., Ho Chi Minh City). These greening activities could benefit biodiversity by supplying new or improved habitat, by improving landscape connectivity, and in some instances by providing the opportunity to establish managed populations of threatened species.

Targets for tree cover are commonly around 40%, while targets for the number of planted trees range from several thousand to almost a hundred million (e.g., Bangkok) (Table 2). This could amount to as much as 14 km^2 additional habitat available for species in a small city (e.g., Wellington, New Zealand), and 68 km^2 in a large city (e.g., Jakarta, Indonesia). If the cities examined here committed to targets of 40% tree cover, this would lead to the re-forestation of 12,917 km^2, an area one and a half times the size of Yellowstone National Park. If this was applied to *all* urban areas worldwide, it would amount to re-forestation of approximately 1.4 million km^2, or nearly half the total area of national parks in the world. An important consideration is that the nature, quality and relevance to biodiversity conservation of tree cover is likely to vary significantly in the impact that it would have on biodiversity in different cities.

3.3 | Prospects for biodiversity in cities

Actions planned by cities to adapt to climate change could potentially counter many of the negative effects of increasing urbanisation on biodiversity, including degradation and loss of habitats as cities sprawl outwards or densify within their existing footprints (Fuller & Gaston, 2009; McKinney, 2002). Explicitly including biodiversity conservation planning in climate change adaptation programmes could also help countries reach their Aichi biodiversity targets, as laid out in the Convention on Biological Diversity (UNEP, 1992). However, the potential for substantial biodiversity conservation benefits are largely unrecognised at present. Although most city climate change adaptation plans (72%) are committing to green infrastructure goals, few of the plans that we surveyed (18%) contained specific intentions to enhance biodiversity. While some of these goals might also be met within biodiversity action plans, the limited acknowledgement within climate adaptation plans perhaps underestimates the real contribution that this approach could provide for achieving both outcomes. Furthermore, integrated planning across these areas could produce much greater outcomes for both. The opportunities for biodiversity conservation will not automatically flow from the development of green infrastructure without explicit planning. It is critical, therefore, that cities act to ensure that urban greening and catchment management are undertaken in a way that is synergistic with biodiversity conservation goals.

One city, Amsterdam, has a specific biodiversity climate adaptation plan that aims to increase and enlarge protected areas to promote resilience to extreme events, and increase connectivity to permit dispersal and migration. Using natural (recruitment and succession) processes to increase landscape heterogeneity will also promote habitat intactness and persistence, improving conditions for threatened species (McKinney, 2002). This case study demonstrates how the two processes – climate adaptation and biodiversity protection – can align with and complement each other. An additional benefit of this approach is that it avoids the need for physical infrastructure that might be able to achieve a similar effect for climate adaptation, but would likely negatively impact biodiversity. Indeed, "physical infrastructure" was the most common type of action in the city plans investigated here, which could mean, for example, even greater alterations to river flows, construction of sea walls, reduced natural connectivity within cities, changes in water storage and availability, and reduced or changed areas of habitat. While this trade-off might be considered appropriate in some instances, the ancillary benefits of nature should also be considered – protected areas and natural recreation spaces for cities deliver a huge array of positive outcomes for people, including improved health and wellbeing (Shanahan et al., 2016), a greater sense of place (Hausmann, Slotow, Burns, & Di Minin, 2016), and greater social cohesion (Cox et al., 2017).

4 | CONCLUSION

Although most cities are embracing the need for urban greening as a key climate change adaptation strategy, very few have recognised the potential co-benefits for biodiversity conservation. Only 18% of 80 city plans analysed (from a global total of 151), included the specific aim of supporting biodiversity. Indeed, biodiversity conservation is not often considered an urban issue (Lepczyk et al., 2017). While some city adaptation responses may exacerbate threats to species and ecosystems, for example the construction of sea walls to protect against sea-level rise, the large-scale diversion of water, and planting of non-native forestry species, we argue that adaptation-driven urban development does not need to be bad news for already imperilled species and ecosystems. We show that cities are important for biodiversity and provide habitat for considerable numbers of threatened species, and therefore the adaptation response of the city may be critical.

Conservation planners must engage in the planning of city climate change adaptation strategies to maximise potential biodiversity gains where possible, and minimise the impacts on existing biodiversity where they may occur. For example, careful selection of species and spatial arrangement of greening activities will substantially influence the potential biodiversity outcomes (Hanski et al., 2012; Shanahan et al., 2011), and including habitat analogues (Lundholm & Richardson, 2010), and active re-introductions (Carroll, Phillips, Lopez-Gonzalez, & Schumaker, 2006) may also be required to support some target species. Where adaptation actions are likely to have negative impacts on habitats or ecosystems, maintaining existing habitat for rare and endangered species, or minimising damage to ecosystems, should also be prioritised. Improvements to the built environment associated with climate adaptation (those actions that fall under "physical infrastructure") also have the potential to limit the negative effects of urbanisation on biodiversity: applying an ecosystem-based adaptation focus could be one effective approach (Brink et al., 2016; Jones, Hole, & Zavaleta, 2012). Identifying areas of high conservation value that could potentially provide these ecosystem services is another critical role for conservation biologists.

The areas where urban population growth is expected to expand the most (Africa, Asia) are also the areas that were less likely to have climate adaptation plans in place in our analysis (although see caveats around geographical bias), and where biodiversity conservation through the development of these plans could potentially have the greatest impact. For example, in Africa only six plans were available to represent all 55 nations, similar to Asia with eight plans; very few compared with the European nations with 28 adaptation plans and North America with 38 plans. Given that many of the most vulnerable cities to the impacts of climate change are located within these regions (World Bank, 2013), assistance for these nations to develop and implement adaptation plans is urgently required. The Green Climate Fund (UNFCCC) is ready to support countries, particularly developing countries, in implementing "high-impact, paradigm-shifting projects and programmes" to reduce greenhouse emissions, and the creation of climate-compatible cities is one of its investment priorities (Cheikhrouhou, 2016). This is an extraordinary opportunity for conservation planners to engage in the climate adaptation planning of highly populated, biologically very diverse, developing cities, and to suggest novel strategies that will both support the sustainable development of the cities and maximise the benefit for biodiversity.

ACKNOWLEDGEMENTS

This work was developed from a workshop supported by the Australian Research Council Centre of Excellence for Environmental Decisions. R.A.F. is supported by an Australian Research Council (ARC) Future Fellowship. N.B. is supported by ARC grant DE150101552. D.F.S. was supported by ARC Discovery Grant DP120102857. We are grateful to the two anonymous reviewers for their insightful and helpful comments and suggestions.

ORCID

Nathalie Butt http://orcid.org/0000-0003-1517-6191

REFERENCES

Aronson, M. F., La Sorte, F. A., Nilon, C. H., Katti, M., Goddard, M. A., Lepczyk, C. A., ... Winter, M. (2014). A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. *Proceedings of the Royal Society B: Biological Sciences*, *281*, 1780.

Balmford, A., Moore, J. L., Brooks, T., Burgess, N., Hansen, L. A., Williams, P., & Rahbek, C. (2001). Conservation conflicts across Africa. *Science*, *291*, 2616–2619.

Barrett, G. W., Freudenberger, D., Drew, A., Stol, J., Nicholls, A. O., & Cawsey, E. M. (2008). Colonisation of native tree and shrub plantings by woodland birds in an agricultural landscape. *Wildlife Research*, *35*, 19–32.

Bekessy, S. A., White, M., Gordon, A., Moilanen, A., Mccarthy, M. A., & Wintle, B. A. (2012). Transparent planning for biodiversity and development in the urban fringe. *Landscape Urban Plan*, *108*, 140–149.

Betsill, M., & Bulkeley, H. (2007). Looking back and thinking ahead: A decade of cities and climate change research. *Local Environment*, *12*, 447–456.

Biagini, B., Bierbaum, R., Stults, M., Dobardzic, S., & McNeeley, S. M. (2014). A typology of adaptation actions: A global look at climate adaptation actions financed through the Global Environment Facility. *Global Environmental Change*, *25*, 97–108.

Birdlife International & NatureServe (2014). Bird species distribution maps of the world. In BirdLife International & NatureServe (Ed.), Cambridge, UK; Arlington, USA: Birdlife International & NatureServe.

Bolund, P., & Hunhammar, S. (1999). Ecosystem services in urban areas. *Ecological Economics*, *29*, 293–301.

Brink, E., Aalders, T., Ádám, D., Feller, R., Henselek, Y., Hoffmann, A., … Wamsler, C. (2016). Cascades of green: A review of ecosystem-based adaptation in urban areas. *Global Environmental Change*, *36*, 111–123.

Broto, V. C., & Bulkeley, H. (2013). A survey of urban climate change experiments in 100 cities. *Global Environmental Change*, *23*, 92–102.

Bulkeley, H. (2010). Cities and the governing of climate change. *Annual Review of Environment and Resources*, *35*, 229–253.

Carroll, C., Phillips, M. K., Lopez-Gonzalez, C. A., & Schumaker, N. H. (2006). Defining recovery goals and strategies for endangered species: The wolf as a case study. *BioScience*, *56*, 25–37.

Cheikhrouhou, H. (2016). *Green Climate Fund Statement on 22 April 2016: From Signatures to Action – GCF Funding Proposals Need to Meet the Ambition of the Paris Agreement*.

Cities, C., & Group, C. L. (2014). *Climate action in megacities: Executive summary*. (C40 Cities). Climate Leadership Group, Arup.

Cox, D. T. C., Shanahan, D. F., Hudson, H. L., Fuller, R. A., Anderson, K., Hancock, S., & Gaston, K. J. (2017). Doses of nearby nature simultaneously associated with multiple health benefits. *International Journal of Environmental Research and Public Health*, *14*, 172.

DeLorme Publishing Company, World Urban Layers (ed ESRI) (2015).

Fuller, R. A., & Gaston, K. J. (2009). The scaling of green space coverage in European cities. *Biology Letters*, *5*, 352–355.

Georgeson, L., Maslin, M., Poessinouw, M., & Howard, S. (2016). Adaptation responses to climate change differ between global megacities. *Nature Climate Change*, *6*, 584–588.

Gill, S. E., Handley, J. F., Ennos, A. R., & Pauleit, S. (2007). Adapting cities for climate change: The role of the green infrastructure. *Built Environment*, *1*, 115–133.

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., & Briggs, J. M. (2008). Global change and the ecology of cities. *Science*, *319*, 756–760.

Hanski, I., von Hertzen, L., Fyhrquist, N., Koskinen, K., Torppa, K., Laatikainen, T., … Haahtela, T. (2012). Environmental biodiversity, human microbiota, and allergy are interrelated. *Proceedings of the National Academy of Sciences*, *109*, 8334–8339.

Hausmann, A., Slotow, R., Burns, J. K., & Di Minin, E. (2016). The ecosystem service of a sense of place: Benefits for human well-being and biodiversity conservation. *Environmental Conservation*, *43*, 117–127.

Huang, M. B., Kang, S. Z., & Li, Y. S. A. (1999). A comparison of hydrological behaviors of forest and grassland watersheds in gully region of the Loess Plateau. *Journal of Natural Resources*, *14*, 226–231.

Hunt, A., & Watkiss, P. (2011). Climate change impacts and adaptation in cities: A review of the literature. *Climatic Change*, *104*, 13–49.

IUCN (2015). *Red list spatial data*. Retrieved from www.iucnredlist.org

Ives, C. D., Lentini, P. E., Threlfall, C. G., Ikin, K., Shanahan, D. F., Garrard, G. E., … Kendal, D. (2016). Cities are hotspots for threatened species. *Global Ecology and Biogeography*, *25*, 117–126.

Jones, H. P., Hole, D. G., & Zavaleta, E. S. (2012). Harnessing nature to help people adapt to climate change. *Nature Climate Change*, *2*, 504–509.

Kalnay, E., & Cai, M. (2003). Impact of urbanization and land-use change on climate. *Nature*, *423*, 528–531.

Lepczyk, C. A., Aronson, M. F. J., Evans, K. L., Goddard, M. A., Lerman, S. B., & MacIvor, J. S. (2017). Biodiversity in the city: Fundamental questions for understanding the ecology of urban green spaces for conservation. *BioScience*, *67*, 799–807.

Lundholm, J. T., & Richardson, P. J. (2010). Habitat analogues for reconciliation ecology in urban and industrial environments. *Journal of Applied Ecology*, *47*, 966–975.

Martin, T. G., & Watson, J. E. M. (2016). Intact ecosystems provide best defence against climate change. *Nature Climate Change*, *6*, 122–124.

Mason, C. F. (2000). Thrushes now largely restricted to the built environment in eastern England. *Diversity and Distributions*, *6*, 189–194.

McGranahan, G., Balk, D., & Anderson, B. (2007). The rising tide: Assessing the risks of climate change and human settlements in low elevation coastal zones. *Environment and Urbanization*, *19*, 17–37.

McKinney, M. L. (2002). Urbanization, biodiversity, and conservation. *BioScience*, *52*, 883–890.

McKinney, M. L. (2006). Urbanization as a major cause of biotic homogenization. *Biological Conservation*, *127*, 247–260.

Moriwaki, R., Watanabe, K., & Morimoto, K. (2013). Urban dry island phenomenon and its impact on cloud base level. *Journal of JCSE*, *1*, 521–529.

Rosenzweig, C., Solecki, W. D., Hammer, S. A., & Mehrotra, S. (2010). Cities lead the way in climate-change action. *Nature*, *467*, 909–911.

Rosenzweig, C., Solecki, W. D., Hammer, S. A., & Mehotra, S. (Eds.) (2011). Urban climate change in context. In *Climate change and cities: First assessment report of the urban climate change research network* (pp. 3–11). Cambridge, UK: Cambridge University Press.

Schwartz, M. W., Jurjavcic, N. L., & O'Brien, J. M. (2002). Conservation's disenfranchised urban poor. *BioScience*, *52*, 601–606.

Seto, K. C., Fragkias, M., Guneralp, B., & Reilly, M. K. (2011). A meta-analysis of global urban land expansion. *PLoS ONE*, *6*, e23777.

Shanahan, D. F., Bush, R., Gaston, K. J., Lin, B. B., Dean, J., & Fuller, R. A. (2016). Health benefits from nature experiences depend on dose. *Scientific Reports*, *6*, 28551.

Shanahan, D. F., Miller, C., Possingham, H. P., & Fuller, R. A. (2011). The influence of patch area and connectivity on avian communities in urban revegetation. *Biological Conservation*, *144*, 722–729.

Solecki, W. D., & Marcotullio, P. J. (2013). Climate change and urban biodiversity vulnerability. In: Elmqvist, T., Fragkias, M., Goodness, J., Güneralp, B., Marcotullio, P. J., McDonald, R. I., Parnell, S., Sendstad, M., Schewenius, M., Seto, K. C., & Wilkinson, C. (Eds.), *Urbanization, biodiversity and ecosystem services: Challenges and opportunities. A global assessment*. Dordrecht, the Netherlands: Springer.

Strauss, B. H., Kulp, S., & Levermann, A. (2015). Carbon choices determine US cities committed to futures below sea level. *Proceedings of the National Academy of Sciences*, *112*, 13508–13513.

UNEP (1992). *Convention on Biological Diversity*. Retrieved from https://www.cbd.int/sp/targets/

United Nations, Department of Economic and Social Affairs, Population Division (2014). *World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352)*. United Nations, New York, NY.

USGS (2013). *15 sec SHAPE: River Network* (ed USGS). Retrieved from https://hydrosheds.cr.usgs.gov/

World Bank (2013). *Turn down the heat: Climate extremes, regional impacts, and the case for resilience*. Washington, DC: World Bank.

SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

Figure S1. Schematic of the content analysis steps and relationships between categories and themes

How to cite this article: Butt N, Shanahan DF, Shumway N, et al. Opportunities for biodiversity conservation as cities adapt to climate change. *Geo: Geography and Environment*. 2018;e00052. https://doi.org/10.1002/geo2.52