

## Methods to Assess Co-Benefits of California Climate Investments

### Climate Adaptation Enhancement

Center for Resource Efficient Communities, UC-Berkeley  
Agreement #15TTD002, Project Order #1, Task 2 Literature Review  
Primary Author: Luciana Rocha

#### I. Background

Under California's Cap-and-Trade program, the State's portion of the proceeds from Cap-and-Trade auctions is deposited in the Greenhouse Gas Reduction Fund (GGRF). The Legislature and Governor enact budget appropriations from the GGRF for State agencies to invest in projects that help achieve the State's climate goals. These investments are collectively called California Climate Investments (CCI).

Senate Bill 862 requires the California Air Resources Board (CARB) to develop guidance on reporting and quantification methods for all State agencies that receive appropriations from the GGRF. Guidance includes developing quantification methodologies for greenhouse gas (GHG) emission reductions and other social, economic, and environmental benefits of projects, referred to as "co-benefits."

This document is one of a series that reviews the available methodologies for assessing selected co-benefits for CCI projects at two phases: estimating potential project-level co-benefits prior to project implementation (i.e., forecasting of co-benefits), and measuring actual co-benefits after projects have been implemented (i.e. tracking of co-benefits). The assessment methodology at each of these phases may be either quantitative or qualitative. As with CARB's existing GHG reduction methodologies, these co-benefit assessment methods will be developed to meet the following standards:

- Apply at the project level
- Align with the project types proposed for funding for each program
- Provide uniform methods to be applied statewide, and be accessible by all applicants
- Use existing and proven tools or methods where available
- Use project level data, where available and appropriate
- Reflect empirical literature

CARB, in consultation with the State agencies and departments that administer CCIs, has selected ten co-benefits to undergo methodology assessment and development. This document reviews available empirical literature on the ***climate adaptation enhancement*** co-benefit and identifies:

- the direction and magnitude of the co-benefit,
- the limitations of existing empirical literature,

- the existing assessment methods and tools,
- knowledge gaps and other issues to consider in developing co-benefit assessment methods
- a proposed assessment method for further development, and
- an estimation of the level of effort and delivery schedule for a fully developed method

## II. Description of co-benefit

The State of California acknowledges that heat-trapping emissions accelerate climate change and prioritizes integrated initiatives to decrease the emission of greenhouse gases.<sup>1</sup> State agencies also understand that previous and ongoing emissions are already impacting California and therefore emphasize the importance of protecting California's residents from climate risks. To this end, the California agencies promote climate adaptation efforts in order to mitigate and prevent negative impacts of climate change.<sup>2</sup>

Climate adaptation refers to activities that help communities adapt to and address the impacts of climate change.<sup>3</sup> The *Safeguarding California Plan* provides the following definition of climate adaptation:

“Adjustment in natural or human systems to a new or changing environment. Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.”<sup>4</sup>

Data suggests that climate change leads to increased occurrence of extreme heat effects, smog, drought, sea level rise, and wildfire, among other significant impacts.<sup>5</sup> Adaptation strategies include efforts to mitigate these effects, such as planting trees to increase shade for homes and buildings and decrease energy use.<sup>3</sup> The State of California has funded critical efforts to assist local and regional agencies in their efforts to assess climate vulnerability and develop adaptation strategies. Key documents include the *2009 California Climate Adaptation Strategy* by the California Natural Resources Agency; its 2014 and 2017 updates, *Safeguarding California: Reducing Climate Risk* and its 2016 Implementation Action Plans; and the *California Adaptation Planning Guide*, by the California Emergency Management Agency and California Natural Resources Agency.<sup>4,6-9</sup>

Research indicates that in addition to directly addressing the climate threat, some strategies for reducing greenhouse gas emissions can also serve as climate adaptation strategies.<sup>6</sup> However, some climate adaptation strategies may conflict with greenhouse gas reduction efforts. For example, the *California Adaptation Planning Guide* notes that a cooling tower that seeks to alleviate the effect of extreme heat (climate adaptation) through air conditioning may increase greenhouse gas emissions.<sup>10</sup> This literature review focuses the following climate adaptation co-benefits:

- **Extreme heat effects moderation.** Activities that reduce greenhouse gas emissions may have the co-benefit of mitigating extreme heat effects.
- **Drought effects moderation.** Activities that reduce greenhouse gas emissions may have the co-benefit of preventing or mitigating drought.
- **Sea level rise and inland flooding adaptation.** Activities that reduce greenhouse gas emissions may have the co-benefit of preventing or preparing for sea level rise and inland flooding.
- **Agricultural productivity conservation.** Activities that reduce greenhouse gas emissions may have the co-benefit of promoting the conservation of agricultural land and enhancing the sustainability of existing agricultural operations.
- **Species habitat conservation.** Activities that reduce greenhouse gas emissions may have the co-benefit of promoting biodiversity and species habitat conservation.
- **Wildfire risk reduction.** Activities that reduce greenhouse gas emissions may have the co-benefit of reducing the risk of catastrophic wildfires.

Table 1, below, illustrates the California Climate Investment programs that may be able to document climate adaptation co-benefits.

**Table 1: CCI Programs Affected by Co-Benefit**

<b>Administering Agency</b>	<b>Program</b>	<b>Likely direction of co-benefit (+ = beneficial change)</b>
<b>Sustainable Communities and Clean Transportation</b>		
CARB	<i>Low Carbon Transportation (LCT)</i>	+
Caltrans	<i>Low Carbon Transit Operations Program (LCTOP)</i>	+
HSRA	<i>High Speed Rail</i>	+
CalSTA	<i>Transit and Intercity Rail Capital Program (TIRCP)</i>	+
SGC	<i>Sustainable Agricultural Lands Conservation (SALC) Program</i>	+
	<i>Transformative Climate Communities (TCC)</i>	+
<b>Energy Efficiency and Clean Energy</b>		
CSD	<i>Low Income Weatherization Program (LIWP)</i>	+
CDFA	<i>State Water Efficiency and Enhancement Program (SWEET)</i>	+
	<i>Healthy Soils Program</i>	+
DWR	<i>Water-Energy Grant Program</i>	+
<b>Natural Resources and Waste Diversion</b>		
DFW	<i>Wetlands and Watershed Restoration</i>	+
CAL FIRE	<i>Forest Health Restoration</i>	+
	<i>Urban and Community Forestry (UCF)</i>	+
CNRA	<i>Urban Greening Program</i>	+

### III. Directionality of the co-benefits

Research indicates that some efforts to reduce greenhouse gas emissions may meaningfully contribute to improved climate adaptation, a *positive co-benefit*. In particular, efforts to increase urban greening, conserve water, restore wetlands and watersheds, and improve soil and forest health both reduce greenhouse gas emissions and promote climate adaptation.

#### IV. Magnitude of the co-benefit

In this section, we explore the literature associated with seven key climate adaptation efforts.

##### *i. Extreme heat effects moderation*

Climate change increases the severity, frequency, and length of heat waves.<sup>11</sup> Urban areas that already experience heat island effects are particularly affected by the heat waves and their health effects, including exacerbation of respiratory conditions, heat stroke, and death.<sup>5</sup> Urban heat islands are caused by the replacement of open land and vegetation by paved surfaces, and the conversion of permeable, moist land to impermeable, dry land.<sup>12</sup> Heat islands can increase greenhouse gas emissions through the need for cooling mechanisms, such as air conditioning systems.<sup>13</sup>

Adaptation activities could include implementing urban greening in strategic locations that provide shade to homes, buildings, and vehicles; implement green space; and promote green infrastructure, including green roofs.<sup>14</sup> One study of a project that planted trees to increase shade for houses reported that energy savings ranged from 7 to 47 percent.<sup>13</sup> In addition, the study found that energy savings are maximized when trees “were planted to the west and southwest of buildings.”<sup>13</sup> Adaptive strategies to reduce heat also focus on efficient building design including using cool roof and pavement materials. Another study reported that planting 50 million trees in California to shade east and west facing walls could reduce peak energy demand by 4.5% over 15 years.<sup>15</sup> In addition, one weatherization program in Philadelphia that offered cool roof coatings reported that participating houses eliminated the vast majority of heat gain through the ceiling and reduced air conditioning use by approximately one-third.<sup>16</sup>

In addition, urban greening efforts can improve the health effects of heat exposure. For example, one modeling study estimated that increased vegetation, in addition to albedo enhancement, could “offset projected increased in heat-related mortality by 40 to 99%” in Atlanta Georgia; Philadelphia, Pennsylvania; and Phoenix, Arizona.<sup>17</sup>

##### *ii. Drought effects moderation*

Climate change is expected to lead to an increase in frequency, duration, and intensity of droughts, which will directly affect biodiversity and agriculture.<sup>9,6</sup> Drought also leads to increased use of groundwater, which will also affect agriculture through potential salt water intrusion.<sup>9</sup>

In addition, the 2009 California Climate Adaptation Strategy identifies seven key water management impacts of global warming: 1) reduced water supply from the Sierra snowpack; 2) changes in water quality; 3) increased evapotranspiration rates from plants, soils and open water surfaces; 4) moisture deficits in non-irrigated agriculture, landscaped areas and natural systems; 5) increased irrigation needs; 6) increased

agricultural water demands due to a longer growing season; and 7) increased urban water use, at possible expense of agricultural water.<sup>6</sup> These increased demands on water can also exacerbate water scarcity during drought conditions.

Adaptive strategies to address the impacts of drought may include efforts to improve water efficiency, reduce per capita water use, encourage the planting of drought-resistant vegetation, engage in sustainable conservation management practices that increase the resiliency of agricultural systems, promote the amount of soil organic matter in soils, and manage watersheds to improve infiltration and groundwater recharge.<sup>10</sup>

### *iii. Sea level rise adaptation*

Research shows that climate change is responsible for sea level rise.<sup>18</sup> Sea level rise will have significant impacts on California residents, most notably due to coastal flooding and displacement.<sup>19</sup> Effects of flooding may include physical injury, death, and property damage.<sup>9</sup> Among the climate adaptation effects included here, sea level rise will also affect agricultural productivity and species habitat conservation.<sup>20</sup> For example, a study of the Elkhorn Slough National Estuarine Research Reserve in Monterey Bay reported that sea level rise will lead to significant marsh loss.<sup>21</sup>

The California Coastal Commission's Sea Level Rise Policy Guidance describes adaptation strategies for sea level rise.<sup>19</sup> Protection strategies include building structures, such as sea walls, to address coastal hazards, such as flooding. Protection efforts could also involve promoting green infrastructure, such as wetlands, to provide buffers for coastal areas. Accommodation strategies could involve changing existing structures to better withstand sea level rise and designing future structures to consider future sea level rise. Finally, retreating strategies include efforts to build new structures away from flood zones, as well as moving existing structures that may be at risk.

The 2014 Safeguarding California Plan also reports that climate change is projected to cause more frequent and severe floods in California, due to an increase in extreme rainfall events.<sup>9</sup> Increased flooding could impact over seven million Californians who live within 500-year floodplains.<sup>9</sup>

In "Managing An Uncertain Future: Climate Change Adaptation Strategies for California's Water," the California Department of Water Resources provides suggestions for adapting to flood events.<sup>22</sup> One key strategy related to CCI programs includes integrating flood management with "watershed management on open space, agricultural, wildlife areas, and other low density lands to lessen flood peaks, reduce sedimentation, temporarily store floodwaters and recharge aquifers, and restore environmental flows."<sup>22</sup>

### *iv. Agricultural productivity conservation*

Climate change has significant impacts on agricultural production. For example, changing air temperatures impact crops and livestock, and increases beyond optimal temperatures may cause declining yield and losses.<sup>23</sup> Other key impacts include more extreme weather events, including both drought and more intense precipitation events; decreased foraging quality and increased feed prices for livestock; and decreased fresh water availability through loss of snowpack and sea level rise.<sup>24</sup>

One key adaptation strategy includes promoting soil conservation and soil health. Healthy soil is critical for ensuring optimum plant health, moderating drought, preventing erosion, and sequestering carbon.

v. *Species habitat conservation*

The 2014 update and the 2017 draft update to the California Climate Adaptation Strategy outline several ways in which climate change negatively impacts biodiversity in California.<sup>4,9</sup> First, accelerated warming increases the spread of invasive species, which can disrupt existing ecosystems. Next, climate change can both increase barriers to species migration and increase migration of other species due to negative effects of rising temperatures on certain habitats. Drought, wildfire, extreme heat events, and increased precipitation induced by climate changes can also threaten natural habitats. In addition, sea level rise caused by climate change can negatively impact biodiversity by threatening the habitat of coastal species and through salt water intrusion of fresh water sources. Other key issues include threats to “coevolved interactions,” including plant-pollinator interactions, as well as general timing issues between seasonal migration and the availability of food.<sup>23</sup>

One review of climate-change adaptation strategies for wildlife management and biodiversity conservation described several activities including increasing the extent of protected areas, designing new restoration sites, protecting movement corridors, and focusing efforts on endangered species.<sup>23</sup> The authors note that several adaptation strategies may not be effective in the long-term in the face of unmitigated climate change. For example, the authors caution, “focusing on protected areas neglects the overall matrix in which these areas are embedded: what happens outside protected areas often influences what happens inside.” However, several of these strategies have short-term benefits of protecting existing habitats of climate-sensitive species.

vi. *Wildfire prevention*

The literature indicates that certain effects of climate change, including warmer temperatures and drier conditions, increase the risk of wildfire.<sup>25</sup> Predictive models estimate that climate change will continue to lead to increased areas of land burned, incidences of wildfire, and intensity of wildfire. These phenomena will contribute to increases in the severity of wildfire seasons and the difficulty of controlling fire.<sup>26,27</sup> In California, increased wildfires due to climate change will also negatively impact the distribution of vegetation and the ability of forests to store carbon and will further increase greenhouse gas emissions.<sup>26</sup>

Wildfire prevention involves reducing fire hazards and increasing forest resilience, which refers to “the ability to cope with stress (also called “resistance”), the capacity to recover from the effects of disturbance and the capability to adapt to stress and change.”<sup>28</sup> Adaptive strategies could involve forest thinning in order to increase space between trees, which increases wildfire resistance. One study of four major wildfires in the United States determined that forest thinning could have contributed to a 98% reduction in carbon dioxide emissions released from tree biomass.<sup>29</sup> An analysis by CAL FIRE found that 1.2 million acres of forested land in California may benefit from benefit from thinning.<sup>27</sup>

## **V. Limitations of current studies and applicability to cci programs**

Studies in the literature and reports prepared by California agencies note that there are some uncertainties associated with the timing and severity of impacts of climate change.<sup>6,9</sup> Researchers have forecast climate change impacts for 2050 and 2100, but acknowledge that several factors—including dispersion of greenhouse gases and air pollutants, ongoing and future climate change mitigation efforts, and natural variation in climates—may influence the effects of climate change.<sup>10</sup> However, while the extent of warming may involve some uncertainties, researchers are clear that “temperatures in California will rise significantly during this century” and the associated impacts will be severe under all available models.<sup>30</sup>

The 2014 Safeguarding California Plan acknowledges that additional research is necessary to quantify the extent and impacts of climate adaptation activities.<sup>9</sup> For example, the report calls for studies that quantify the benefits of ecosystem services that reduce climate risks; baseline carbon information associated with natural systems; and carbon sequestration and water saving potential of compost use in agricultural settings such as irrigated croplands and rangelands. While the CALifornia natural and working LANDs Carbon Model (CALAND) will provide information about baseline carbon information about the Fourth Climate Change Assessment of the Climate Change Research Plan will provide information about carbon sequestration and water saving potential, these research tools are not yet available to the public.

While there is scientific consensus on the necessity of adapting to ongoing and future climate impacts, the literature describes a lack of consensus on how to prioritize adaptation measures and how they are selected to evaluate specific projects.<sup>31–36</sup> In describing the lack of standardized tracking of adaptation activities across nations and cities, Araos et al. state, “the major obstacle to such efforts remains the absence of appropriate data sources that fulfill the 4Cs of adaptation tracking: a consistent and operational conceptualization of adaptation, comparable units of analysis, comprehensive datasets on adaptation action, and coherence with our understanding of what constitutes adaptation.”<sup>31</sup>

## **VI. Existing quantification methods and tools**



**General climate adaptation quantification measures.** The literature describes a wide range of adaptation indicators, measures, and evaluation frameworks. Adaptation measures are generally described in the context of an existing program or initiative, such as the United Nations Framework Convention on Climate Change.<sup>36</sup> Several programs do not tailor their projects to achieve certain indicators, but rather develop indicators to measure progress of certain policies and plans. For example, a project with the objective of reducing the vulnerability of coastal systems and enhancing the adaptation capacity of coastal populations may develop indicators that include “length of coastline covered by project interventions” and “number of different resilience-enhancing measures employed by project, combined with number of ecological and geomorphological systems addressed.”<sup>37</sup>

The academic and agency literature, including ongoing work by the E.O. B-30-15 Technical Advisory Committee to the Governor’s Office of Planning and Research, generally describes two key types of adaptation indicators: process and outcome. CCI project applicants will likely be limited to reporting on process measures of adaptation, as it may be too difficult to attribute changes in climate change adaptation outcomes to individual projects. Table 2 describes process and outcome adaptation measures.

**Table 2:** *Types of adaptation measures, adapted from Ford et al. (2013)*<sup>34</sup>

Type of measure	Tracking approaches	Characteristics	Data sources	Strengths	Limitations
Preparedness-, process-, and policy-based	Process-based approaches: <i>process through which adaptations are developed and implemented in pursuance of a desired outcome or objective</i>	Comparison of adaptation characteristics to theoretically and empirically derived characteristics of adaptation success and best practice	Adaptation inventories	Capture the key processes that are believed to underpin effective and successful adaptation	Unproven link to adaptation success
Outcome-based	Outcome evaluation: <i>reduced negative climate change impacts</i>	Track climate-related losses, mortality, and morbidity, over time and in relation to adaptation	Natural hazard loss databases (e.g., emergency events database)	Quantification of adaptation progress and effectiveness  Metrics can be monitored over time	Difficulty of inferring causality between outcome and adaptation

Tools used to rank the relative importance of possible adaptations include cost-effectiveness and cost-benefit calculations, in addition to indices that assign weights to evaluation criteria. For example, the Index of Usefulness of Practices for Adaptation includes “robustness or flexibility of the solution” as an evaluation criteria and requires users to rank their adaptation strategy as high, moderate, or low robustness and/or flexibility.<sup>32</sup>

Climate adaptation measures and indicators generally required program planners to describe their efforts qualitatively.<sup>31,33,35–38</sup> For example, the U.S. EPA developed a tool to measure urban communities' resilience to climate change that incorporates qualitative indicators.<sup>39</sup> One qualitative indicator related to water adaptation, for example, asks: "to what extent have efforts been made to reduce water demand?" Some programs also describe quantitative indicators of climate adaptation.<sup>39</sup> For example, one of the U.S. EPA's quantitative indicators for their tool that measures resilience to climate change is "number of wetland and freshwater species at risk (rare, threatened, or endangered).<sup>39</sup> The literature also describes more complex quantitative measures that are likely beyond the scope of CCI project-level applications. For example, one review of climate adaptation strategies in the European Union provides a quantification measure for total green roof potential. The calculation involves assessing the share of total city area covered by roofs, the roof area per inhabitant in a typical urban area, the share of roofs that are feasible for vegetation, and the total area of the city, among other measures.

**California-specific adaptation measures.** In general, documents developed by California agencies provide several suggestions for climate adaptation strategies, but have only recently begun issuing guidance for measuring adaptation efforts. In many cases, this lack of specification ensures that the intended audience has the flexibility to adapt strategies to their region, resources, and goals. One key source of adaptation measures is the draft 2017 update to *Safeguarding California*.<sup>4</sup> In this section, we describe existing methods to categorize and prioritize climate adaptation efforts at both the pre-award estimation (phase 1) and post-award tracking (phase 2) stages.

*i. Extreme heat effects moderation*

The key CCI programs that will address extreme heat effects moderation may include Transformative Climate Communities, Urban Greening, Urban Forestry, the Wetlands and Watershed Restoration program, and the Low-Income Weatherization Program. Some CCI programs will be able to use application requirements to quantify their climate adaptation activities. For example, the Urban Forestry program already requires certain program applicants to use urban carbon accounting tools from the U.S. Department of Agriculture Forest Service in order to estimate greenhouse gas reductions. These tools (the Center for Urban Forest Research's **Tree Carbon Calculator** and the **i-Tree Streets** software) also allow users to calculate the amount of carbon stored by selected trees and the estimated effects of tree shade on building energy use.

The literature indicates that trees and vegetation are most useful as a mitigation strategy when planted in strategic locations around buildings or to shade pavement in parking lots and on streets.<sup>13</sup> For example, researchers have found that planting deciduous trees or vines to the west is typically most effective for cooling a building, especially if they shade windows and part of the building's roof.<sup>40</sup> Potential quantification efforts for extreme heat effects could include the number of shade-providing trees and plants that were planted in certain directions around buildings.

The California Environmental Protection Agency's **Urban Heat Island Index** allows users to determine a "positive temperature differential over time between an urban census tract and nearby upwind rural reference points at a height of two meters above ground level, where people experience heat."<sup>41</sup> Comparing the magnitude of the heat island that applicants are targeting could provide context for the climate adaptation significance of a proposed project.

Tracking climate adaptation efforts in phase 2 will likely involve process measures related to certain activities in the project time period. For example, program applicants could track the number of trees planted or number of cool roofs installed on a regular basis. Attributing specific extreme heat effects moderation outcomes to these sorts of project actions would be challenging without modelling software.

The draft 2017 update to *Safeguarding California* suggests the following climate impact metrics for extreme heat effects: (1) increase in Cooling Degree Days since 1950, (2) heat death, hospitalizations, and emergency room visits, (3) heat stress impacts to crop and livestock, and (4) average annual extreme heat Land Surface Temperature (LST) difference between urban and rural areas.<sup>4</sup>

#### *ii. Drought effects moderation*

Applicants to the CCI programs that promote drought effects moderation – the SWEEP program and the DWR Water-Energy Efficiency program – are also required to estimate water savings for their projects using the **SWEEP Water Savings Assessment Tool** and the **ARB GHG Calculator Tool**, respectively. In addition, SWEEP program applicants already receive extra consideration during the review process for 1) demonstrating reduced groundwater pumping within critically over-drafted groundwater basins and 2) increasing soil organic matter, which increases the water-holding capacity of soil. Tracking climate adaptation efforts in phase 2 could also involve assessing the magnitude of water savings at regular intervals. In addition, the Urban Greening program may track the amount of drought-tolerant vegetation that is planted. The Healthy Soils program also helps moderate the effect of drought as healthy soils help retain water. Metrics associated with the amount of soil organic matter that program grantees develop could help measure adaptation efforts as well.

The draft 2017 update to *Safeguarding California* suggests the following climate impact metrics for drought effects: (1) drought-related idled land, (2) percentage of rainfall as total precipitation, and (3) trend in acreage of elevated tree mortality.<sup>4</sup>

#### *iii. Sea level rise and inland flooding adaptation*

The key CCI program that will address sea level rise is the Wetlands Restoration for Greenhouse Gas Reduction Grant Program. The State of California suggests the use of the **Coastal Storm Modeling System (CoSMoS)**, developed by the United States

Geological Survey, to predict sea level rise and coastal flooding.<sup>42</sup> **Cal-Adapt**, a project of the California Energy Commission, California Natural Resources Agency, and Public Interest Energy Research Program, includes a map that display CoSMoS' coastal flooding projections.<sup>43</sup> Another tool to identify and estimate the climate adaptation co-benefits in phase 1 is the U.S. Environmental Protection Agency's **CREAT Climate Scenarios Projection Map**.<sup>44</sup> This simple map displays regions at risk for sea level rise impacts. Tracking efforts in phase 2 would largely be focused on process measures for the project. It will be very difficult to assess how projects affect sea level rise in their target areas on a short-term basis. Program applicants could potentially measure changes in sea level near their target areas each year, but it would be challenging to attribute changes to the project instead of other greenhouse gas reduction efforts and ongoing climate change concerns.

The Department of Water Resources also developed the Climate Change Handbook for Regional Water Planning to assist individuals involved in water management planning with incorporating considerations for the impact of climate change.<sup>45</sup> In particular, one section of the guide provides suggestions for "Evaluating Projects, Resource Management Strategies, and [Integrated Regional Water Management] Plan Benefits with Climate Change." The Handbook suggests the following performance metrics to potentially quantify flood management project adaptations:

- "Acres of a certain habitat or floodplain function restored/protected,
- Volume of natural flood storage provided,
- Storm return period used for planning, and
- Expected damage resulting from a certain return period storm."<sup>45</sup>

The report also reviews several other adaptation strategies that could help mitigate strategies. For example, the guide highlights the key role of habitat enhancement and restoration on integrated flood management, which indicates that the Wetlands Restoration for Greenhouse Gas Reduction Grant Program will address inland flooding as well as sea level rise. The guide notes, "the natural storage provided by riparian wetlands can serve as buffers that absorb peak flows and provide slow releases after storm events."<sup>45</sup> Suggested performance measures are "broad," due to the broad nature of resource management. They include:

- "Presence/absence of key indicator species,
- Acres of a certain habitat or floodplain function restored/protected, and
- Volume of natural flood storage provided."<sup>45</sup>

Similarly, the Healthy Soils Program, Forest Health Program, and Urban and Community Forestry Program could be critical to flood management. Forests have the capacity to regulate the flow of water into the ground through tree canopies, and trees also have the capacity to consume large quantities of water. Healthy Soil also reduces runoff when compared to degraded soil, which assists in flood management.

One potential source of adaptation metrics is the U.S. Environmental Protection Agency's Flood Resilience Checklist.<sup>46</sup> The checklist is intended to help communities assess their capacity to avoid flood, reduce flood damage, and recover from floods. The yes/no checklist includes questions such as:

- “Has the community adopted tree protection measures?”
- Has the community adopted riparian and wetland buffer requirements?
- Has the community implemented strategies to reduce storm water runoff from road, driveways, and parking lots?”

The draft 2017 update to *Safeguarding California* suggests the following climate impact metrics for sea level rise and inland flooding: (1) disaster funds disbursed to fix transportation assets after climate events (flood, wildfire, landslide), (2) average observed sea level rise in inches over the past century, (3) number of Californians living in flood-prone areas, (4) coastal ocean temperature change over the past century, and (5) miles of transportation network impacted by coastal and/or inland flooding.<sup>4</sup>

*iv. Agricultural productivity conservation*

The key CCI programs that will address agricultural productivity conservation are the Sustainable Agricultural Lands Conservation Program, the Wetlands and Watershed Restoration, the Healthy Soils program, the Alternative Manure Management Practices program, and the State Water Efficiency and Enhancement Program.

The California Healthy Soils Action Plan describes climate adaptation activities that help protect and restore soil organic matter.<sup>47</sup> Relevant activities include expanding the use of soil amendments that increase the carbon content of soils (e.g., compost and biosolids co-compost), balancing the addition of synthetic inputs with soil carbon and soil organic matter buildup, supporting farmland conservation, promoting on-farm water storage and appropriate groundwater recharge.

The State Water Efficiency and Enhancement Program focuses on transitioning agricultural production from groundwater pumped on-farm to centralized pressurized irrigation delivery systems. As applicants are required to quantify on-farm water consumption and water management using the **SWEEP Water Savings Assessment Tool** described in section VI(ii) above, it would be feasible to estimate ranges for decreased consumption.

The Department of Water Resources' **Proposed Methodology for Quantifying the Efficiency of Agricultural Water Use** also provides fairly straightforward calculations of agricultural water management.<sup>48</sup> For example, the document provides methods for assessing: 1) the Crop Consumptive Use Fraction, which quantifies the efficiency of water use for the purpose of crop evapotranspiration; 2) the Agronomic Water Use Fraction, which quantifies the efficiency of water use for the purpose of crop evapotranspiration and agronomic use; and 3) the Total Water Use Fraction, which

quantifies the efficiency of water use to meet crop consumptive use, crop agronomic use, and environmental use.

The draft 2017 update to *Safeguarding California* suggests the following climate impact metrics for agricultural productivity conservation include (1) heat stress impacts to crop and livestock and (2) percentage of rainfall as total precipitation, among others.<sup>4</sup>

v. *Species habitat conservation*

The three key CCI programs that will address species habitats are the Wetlands and Watershed Restoration program, the Sustainable Agricultural Lands Conservation Program, and the Forest Health program. Grant program applicants in these programs are already tasked with explaining the significance of their proposed project from a climate change adaptation perspective.

Quantification methods that assess the impact of conservation and restoration activities on species habitat often involve modeling. For example, in order to identify conservation priorities for the Mohave ground squirrel, the California Department of Fish and Wildlife modeled multiple scenarios to assess the potential effects of climate change on the species.<sup>8</sup>

Many argue that habitat conservation should not only be measured in terms of acres conserved, but also in terms of the quality of habitats. The Environmental Defense Fund's **Habitat Quantification Tool**, for example, considers habitat quality in order to assign certain scores to conservation sites for select species.<sup>49</sup> For example, the Habitat Quantification Tool for Chinook Salmon in California's Central Valley assigns a score of 0.75 out of 1 for sites with "Direct Partial Connectivity," where "Water and fish move on and off the floodplain through a conduit, like a slough or irrigation canal." However, this tool is not available free-of-charge and only provides suggestions for a few species.

The California Essential Habitat Connectivity Project, funded by the California Department of Fish and Wildlife and the California Department of Transportation, provides a tool to assess essential habitat connectivity through Geographic Information System (GIS) Data.<sup>50</sup> The **Areas of Conservation Emphasis (ACE-II) map** identifies and visualizes sensitive habitats, biological richness, stressors, and essential habitat connectivity data in order to allow users to identify conservation priorities in California.<sup>51</sup>

The **California State Wildlife Action Plan (SWAP)** aims to help protect species and their habitats from climate risks through improving habitat connectivity and protecting climate refugia.<sup>20</sup> SWAP provides a wide variety of documents that may be useful in quantifying and prioritizing species habitat conservation efforts. For example, SWAP includes priority conservation targets for vegetation communities by ecoregion, which are ranked according to criteria of endemism, total biodiversity, and vulnerability. An excerpt from one of these tables is replicated in Table 3. CCI applicants could use this ranking to assess the quality of the habitats that program applicants propose to restore.

SWAP also offers other information about key conservation units and targets that may help CCI assess program applications. For example, for each region in California, SWAP defines: 1) key ecological attributes considered the most important for the viability of the targets and their associated species; 2) species of greatest conservation need; and 3) pressures on conservation targets.

**Table 3.** Excerpt from SWAP priority conservation targets for vegetation communities by ecoregion

Table D-9 Central California Coast Ecoregion		
U.S. National Vegetation Classification macrogroup	Common Name	Target Rank
Western North America Vernal Pool	Vernal Pools	4
California Annual and Perennial Grassland	California Grassland and Flowerfields	4
California Forest and Woodland	California Foothill and Valley Forests and Woodlands	4
Western North American Freshwater Marsh	Freshwater Marsh	5
Warm Southwest Riparian Forest	American Southwest Riparian Forest and Woodland	5
Western North American Temperate Grassland and Meadow	Western Upland Grasslands	7

In phase 1, applicants would likely estimate potential project-level co-benefits by assessing planned activities associated with climate adaptation related to species and habitat conservation. In phase 2, the ability of CCI program applicants to track changes in species and habitat conservation will depend on available databases that record the numbers and locations of endangered and threatened species. However, it may be difficult for programs to link changes in species numbers to their efforts. Some programs do not collect tracking information about species and habitat conservation. For example, the 2005-2014 Implementation Evaluation for SWAP notes that grantees use reports and surveys to report on objectives and the expected results of their activities.<sup>52</sup> However, grantees do not report on outcomes, such as changes in ecosystem or species health.

The draft 2017 update to *Safeguarding California* suggests the following climate impact metrics for species habitat conservation: (1) species ranges, (2) area of plant community types, (3) species abundance and diversity, (4) fish and wildfire mortality events, (5) timing of life cycle events (phenology), and (6) human-wildlife conflicts.<sup>4</sup>

vi. *Wildfire prevention*

The key program that will address wildfire prevention are the Forest Health Program, to the extent that project applicants are promoting forests that are resilient to fire. Wildfire prevention will also promote species habitat conservation, as described above.

The California Department of Forestry and Fire Protection's **Fire and Resource Assessment Program** has identified priority landscapes that contain at-risk carbon stocks and forest ecosystems considered to be of high value to the people of California.<sup>20</sup> In phase 1, program applicants can easily identify their target areas on the priority landscape map, which are already classified as high/medium/low priority. In addition, **Cal-Adapt** offers a fire risk tool that allows users to identify the increase in area burned by wildfire under different climate models and scenarios.<sup>53</sup> In phase 2, tracking climate adaptation progress could involve periodically submitting process measures associated with wildfire prevention (e.g., number of acres of forest treated). Outcome measures, like numbers of wildfires in project areas since project implementation compared to historical data, may be difficult to attribute to project activities alone rather than short-term variability in the climate and other ongoing fire prevention efforts. However, current research projects for the Fourth Climate Change Assessment of the Climate Change Research related to wildfire modeling may be able model impact of fire prevention treatments on wildfire risk reduction in the future.

The draft 2017 update to *Safeguarding California* suggests the following climate impact metrics for wildfire prevention: (1) soil burn severity, (2) deforestation after wildfire, and (3) 10-year average of acres burned.<sup>4</sup>

## VII. Knowledge gaps and other issues to consider in developing co-benefit quantification methods

Not all climate adaptation strategies will be equally urgent in all regions. For example, the *California Adaptation Planning Guide: Understanding Regional Characteristics* provides local considerations for assessing climate vulnerability and developing adaptation strategies.<sup>10</sup> Little change in heat wave incidence is expected in the North Coast Region by 2050, while the South Coast Region is expected to experience three to five times more heat waves by 2050. The wildfire risk in the Central Coast region is expected to increase by four to six times compared to current conditions, while there is little change in expected fire risk in the Bay Area region. Given limited resources, some CCI program applicants will prioritize different climate adaptation strategies.

**Extreme heat effects moderation.** Projects funded by the Urban Greening and Urban Forestry programs may have significant effects on extreme heat effects moderation at the project level. For example, tree plantings could reduce temperature extremes and air conditioning-related energy consumption in project areas substantially. These co-benefits could also be aggregated at the program level, but are likely not significant at the level of the whole GGRF.

**Drought effects moderation.** Individual projects that conserve water, such as the Forest Health, SWEEP, and Water-Energy Efficiency programs, are likely to significantly improve drought effects moderation co-benefits at the project level by improving water use efficiency, and these effects can be aggregated to assess co-benefits at the program level. However, it will be more difficult to assess the drought moderation co-



benefits of other CCI projects and programs that have impacts on water supply. The Sustainable Agricultural Lands Conservation program keeps land in existing agricultural use, and thus maintains current water use patterns in the project area. Projects funded by the Healthy Soils and Waste Diversion programs do improve the water-holding capacity of soils by increasing soil organic matter content, but in the absence of soil testing data the impacts of this on drought moderation will likely be very difficult to detect, at either project or program levels, in the face of general climate and rainfall variability. Overall, these drought effects moderation co-benefits are not likely to be significant at the level of the whole GGRF.

***Sea level rise adaptation.*** Individual projects within the Wetlands and Watershed Restoration program may contribute to sea level rise adaptation by protecting or restoring coastal wetlands. These co-benefits could possibly be significant at the project level if the project creates sufficient buffer between tidal levels and built structures or infrastructure that needs protection. However, because sea level rise is a very gradual phenomenon that will affect the entire coastline and tidally influenced areas such as the Delta, the contribution of these individual projects to overall sea level rise adaptation at the program or GGRF level is likely to be insignificant.

***Inland flooding adaptation.*** Individual projects within the Wetlands and Watershed Restoration program, Healthy Soils program, and Forest Health Restoration/Urban Forestry program may have a significant flood adaptation co-benefit, as measured by the amount of floodplain that is restored, amount of land improved through soil amendments, and number of trees planted. These effects may also be significant at a program level, and given the large scale of some restoration projects funded by CCIs, could be significant at the level of the whole GGRF.

***Agricultural productivity conservation.*** Individual projects funded by the Healthy Soils, Waste Diversion or SALC projects may have a significant effect on agricultural productivity at the project level, as assessed by the amount of land that is conserved or improved through soil amendments. These effects may be moderately significant at the program level, but are not likely to be significant at the level of the whole GGRF.

***Species habitat conservation.*** Individual projects funded by the Wetlands and Watershed Restoration or Forest Health Restoration programs may have a significant species habitat conservation co-benefit, as measured by the amount of habitat that is being conserved or efforts to maintain wildlife corridors. These effects may also be significant at a program level, and depending upon the size of the projects and the conservation importance of the species in question, could be significant at the level of the whole GGRF.

***Wildfire prevention.*** Because reduction of wildfire risk is a central purpose of some projects funded by the Forest Health Restoration program, these are likely to have a significant wildfire prevention co-benefit at both the project and program levels. Given the large scale of some forest restoration projects, these co-benefits could also be significant at the level of the whole GGRF.

### **VIII. Proposed method/tool for use or further development**

Given these findings, we offer the following recommendations for methods and tools for assessment of climate adaptation enhancement co-benefits, schedule for development of guidance documents, and applicant data needs.

#### *Methods for estimation prior to award of CCI funds (Phase 1):*

In order to assess climate adaptation efforts across different CCI programs and climate adaptation strategies, the UC Berkeley team recommends developing a checklist that will record the presence or absence of an expected co-benefit (e.g., a “yes/no” approach). This approach would enable each CCI project applicant to identify whether it is contributing to a climate adaptation co-benefit, but would not allow for any characterization of the magnitude of that contribution.

Developing tailored checklists for climate adaptation strategies that are relevant to CCI programs will ensure that the burden on applicants for assessing climate adaptation co-benefits remains low. The checklist could include a “not applicable” option to ensure that grantees are not being penalized for failing to engage in climate adaptation strategies that are not relevant to their projects.

Tables 4-10 below present potential assessments of climate adaptation by topic area. Examples of yes/no assessment metrics are included in each table.

*i. Extreme heat effects moderation*

Table 4 shows recommended measures to assess the extent of extreme heat effects moderation.

<b>Table 4. Select potential measures for extreme heat effects moderation</b>	
<b>Measure (Y/N)</b>	<b>Assessment(Y/N)</b>
Will the project plant trees that will provide shade to buildings or homes?	<input type="checkbox"/> Yes <input type="checkbox"/> No
Will the project plant trees that will shade parking lots?	<input type="checkbox"/> Yes <input type="checkbox"/> No
Will the project include activities that reduce the urban heat island effect?	<input type="checkbox"/> Yes <input type="checkbox"/> No
Will the project result in net cooling carbon dioxide emission reductions from buildings?	<input type="checkbox"/> Yes <input type="checkbox"/> No
Will the project install cool roofs?	<input type="checkbox"/> Yes <input type="checkbox"/> No

*ii. Drought effects moderation*

Table 6 shows recommended measures to assess the extent of drought effects moderation.

<b>Table 6. Select potential measures for drought effects moderation</b>	
<b>Measure (Y/N)</b>	<b>Assessment (Y/N)</b>
Is this project setting up a sustainable mechanism to conserve water?	<input type="checkbox"/> Yes <input type="checkbox"/> No
Is this project promoting healthy soil?	<input type="checkbox"/> Yes <input type="checkbox"/> No

*iii. Sea level rise and inland flooding adaptation*

Table 7 shows recommended measures to assess the extent of special habitat conservation.

<b>Table 7. Select potential measures for sea level rise adaptation</b>	
<b>Measure (Y/N)</b>	<b>Assessment (Y/N)</b>
Does the project include any of the following flood protection measures?	
Floodplain restoration or protection	<input type="checkbox"/> Yes <input type="checkbox"/> No
Forest/tree restoration or protection	<input type="checkbox"/> Yes <input type="checkbox"/> No
Healthy soil restoration	<input type="checkbox"/> Yes <input type="checkbox"/> No
Is the project located in region at risk for sea level rise impacts, according to CREAT Climate Scenarios Projection Map, the Coastal Storm Modeling System (CoSMoS), or another mapping tool?	<input type="checkbox"/> Yes <input type="checkbox"/> No

iv. *Agricultural productivity conservation*

Table 8 shows recommended measures to assess the extent of agricultural productivity conservation.

<b>Table 8. Select potential measures for agricultural productivity conservation</b>	
<b>Measure (Y/N)</b>	<b>Assessment (Y/N)</b>
Is this project conserving farmland?	<input type="checkbox"/> Yes <input type="checkbox"/> No
Is this project promoting healthy soil?	<input type="checkbox"/> Yes <input type="checkbox"/> No
Is this project reducing on-farm groundwater consumption?	<input type="checkbox"/> Yes <input type="checkbox"/> No

v. *Species habitat conservation*

Table 9 shows recommended measures to assess the extent of special habitat conservation.

<b>Table 9. Select potential measures for species habitat conservation</b>	
<b>Measure (Y/N)</b>	<b>Assessment (Y/N)</b>
Is this project restoring land that contains threatened or endangered species, or provides	<input type="checkbox"/> Yes <input type="checkbox"/> No
Is this project maintaining an endangered or threatened species in its historical habitat?	<input type="checkbox"/> Yes <input type="checkbox"/> No
Is this project constructing or maintaining wildlife corridors and habitat connectivity?	<input type="checkbox"/> Yes <input type="checkbox"/> No

\*Or identified as a species of greatest conservation need in SWAP

vi. *Wildfire prevention*

Table 10 shows recommended measures to assess the extent of wildfire prevention.

<b>Table 10. Select potential measures for wildfire prevention</b>	
<b>Measure (Y/N)</b>	<b>Assessment (Y/N)</b>
Does this project target a "priority landscape for preventing wildfire threats," as defined by the California Department of Forestry and Fire Protection's Fire and Resource Assessment Program?	<input type="checkbox"/> Yes <input type="checkbox"/> No
Is this project conducting forest treatments to prevent wildfires?	<input type="checkbox"/> Yes <input type="checkbox"/> No

*Methods for assessment after award of CCI funds (Phase 2):*

Because climate adaptation co-benefits will, in most cases, take many years to manifest, short-term tracking of the co-benefits after the award of CCI funds will be limited to verifying that the project characteristics indicated in the Phase 1 estimations came into being as anticipated. This would simply involve reporting on the same

checklist items one or more years after the completion of the project in question to identify any divergences between estimated co-benefits and as-built co-benefits.

### *Schedule*

To keep the burden as low as possible for applicants, the UC Berkeley team would limit checklist items to three or four per program and tailor questions to ensure that they are very specific to potential projects. The steps required to develop this approach would include:

- Review project applications or consult with program staff and climate experts as necessary to further understand the proposed scope of CCI projects across various climate adaptation criteria;
- Beginning with the preliminary checklist items in Tables 4-10 above, refine three to four checklist items for each program based on this literature review, the project applications, and more targeted literature searches for potential checklist items if necessary; and
- Develop the checklists.

For the yes/no checklist approach, the UC-Berkeley team could execute these steps and develop draft co-benefit assessment methodology within two months of ARB's instructions to proceed.

### *Data needs*

The data inputs that would be required of the project applicants are illustrated in Figures 4-10. Most of these data inputs are items that are (a) already included in project applications, (b) would be readily available to project applicants, or (c) would be discovered through consultation with a look-up table (e.g. a list of endangered or threatened species) or map (e.g. the CREAT Climate Scenarios Projection Map) provided in the methodology assessment guidance. Some checklist items related to extreme heat effects moderation could require additional quantification (e.g., using the Urban Heat Island Index data to determine average heat island effect).

## **References**

1. The State of California. Statewide Response to Climate Change. Available at:  
<http://climatechange.ca.gov/state/>. (Accessed: 30th March 2017)
2. The State of California. Adaptation Programs - California Climate Change. Available at:  
<http://climatechange.ca.gov/adaptation/>. (Accessed: 29th March 2017)
3. U.S. Environmental Protection Agency. Adapting to Climate Change. Available at:  
<https://www.epa.gov/climatechange/adapting-climate-change>. (Accessed: 22nd March 2017)
4. California Natural Resources Agency. *Draft Report, Safeguarding California Plan: 2017 Update*. (2017).
5. U.S. Environmental Protection Agency. Climate Impacts on Human Health. Available at:  
<https://www.epa.gov/climate-impacts/climate-impacts-human-health>. (Accessed: 22nd March 2017)
6. California Natural Resources Agency. *2009 California Climate Adaptation Strategy*. (2009).
7. California Natural Resources Agency. *2016 Safeguarding California: Implementation Action Plans*. (2016).
8. California Natural Resources Agency. *Biodiversity and Habitat Sector Plan*. (2016).
9. California Natural Resources Agency. *Safeguarding California: Reducing Climate Risk An update to the 2009 California Climate Adaptation Strategy*. (2014).
10. California Emergency Management Agency and California Natural Resources Agency. *California Adaptation Planning Guide: Understanding Regional Characteristics*. (2012).
11. U.S. Environmental Protection Agency. Climate Change and Heat Islands. Available at:  
<https://www.epa.gov/heat-islands/climate-change-and-heat-islands>. (Accessed: 22nd March 2017)

12. U.S. Environmental Protection Agency. Learn About Heat Islands. Available at:  
<https://www.epa.gov/heat-islands/learn-about-heat-islands>. (Accessed: 23rd March 2017)
13. U.S. Environmental Protection Agency. *Heat Island Reduction Activities*. (2008).
14. Gill, S. E., Handley, J. F., Ennos, A. R. & Pauleit, S. Adapting cities for climate change: the role of the green infrastructure. *Built Environ.* **33**, 115–133 (2007).
15. McPherson, E. G. & Simpson, J. R. Potential energy savings in buildings by an urban tree planting programme in California. *Urban For. Urban Green.* **2**, 73–86 (2003).
16. Blasnik, M. *Impact Evaluation of the Energy Coordinating Agency of Philadelphia's Cool Homes Pilot Project*. (2004).
17. Stone Jr., B. *et al.* Avoided Heat-Related Mortality through Climate Adaptation Strategies in Three US Cities. *PLOS ONE* **9**, e100852 (2014).
18. Church, J. A. & White, N. J. A 20th century acceleration in global sea-level rise. *Geophys. Res. Lett.* **33**, L01602 (2006).
19. California Coastal Commission. *California Coastal Commission Sea Level Rise Policy Guidance*. 121–162 (California Coastal Commission, 2015).
20. California Department of Fish and Wildlife. *California State Wildlife Action Plan, 2015 Update: A Conservation Legacy for Californians*. (2015).
21. Climate Change: Spotlight on Elkhorn Slough. Available at:  
<https://www.wildlife.ca.gov/Conservation/Climate-Science/Case-Studies/Elkhorn-Slough>.  
(Accessed: 23rd March 2017)
22. California Department of Water Resources. *Managing an Uncertain Future: Climate Change Adaptation Strategies for California's Water*. (2008).

23. Mawdsley, J. R., O'malley, R. & Ojima, D. S. A Review of Climate-Change Adaptation Strategies for Wildlife Management and Biodiversity Conservation. *Conserv. Biol.* **23**, 1080–1089 (2009).
24. Watson, J. E. M., Rao, M., Ai-Li, K. & Yan, X. Climate Change Adaptation Planning for Biodiversity Conservation: A Review. *Adv. Clim. Change Res.* **3**, 1–11 (2012).
25. Proceedings of the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires (PDF Download Available). *ResearchGate* Available at:  
  
[https://www.researchgate.net/publication/259890905\\_Proceedings\\_of\\_the\\_Fourth\\_International\\_Symposium\\_on\\_Fire\\_Economics\\_Planning\\_and\\_Policy\\_Climate\\_Change\\_and\\_Wildfires](https://www.researchgate.net/publication/259890905_Proceedings_of_the_Fourth_International_Symposium_on_Fire_Economics_Planning_and_Policy_Climate_Change_and_Wildfires).  
  
(Accessed: 23rd March 2017)
26. Fried, J. S., Torn, M. S. & Mills, E. The Impact of Climate Change on Wildfire Severity: A Regional Forecast for Northern California. *Clim. Change* **64**, 169–191 (2004).
27. Westerling, A. L. & Bryant, B. P. Climate change and wildfire in California. *Clim. Change* **87**, 231–249 (2008).
28. Building resilience for adaptation to climate change in the agriculture sector. Available at: <http://www.fao.org/docrep/017/i3084e/i3084e00.htm>. (Accessed: 23rd March 2017)
29. Hurteau, M. D., Koch, G. W. & Hungate, B. A. Carbon protection and fire risk reduction: toward a full accounting of forest carbon offsets. *Front. Ecol. Environ.* **6**, 493–498 (2008).
30. California Climate Change Center, California Energy Commission, (first) & California Natural Resources Agency. *Our Changing Climate 2012: Vulnerability & Adaptation to the Increasing Risks from Climate Change in California*. (2012).



31. Araos, M. *et al.* Climate change adaptation planning in large cities: A systematic global assessment. *Environ. Sci. Policy* **66**, 375–382 (2016).
32. Debels, P. *et al.* IUPA: a tool for the evaluation of the general usefulness of practices for adaptation to climate change and variability. *Nat. Hazards* **50**, 211–233 (2009).
33. Doherty, M., Klima, K. & Hellmann, J. J. Climate change in the urban environment: Advancing, measuring and achieving resiliency. *Environ. Sci. Policy* **66**, 310–313 (2016).
34. Ford, J., Berrang-Ford, L., Lesnikowski, A., Barrera, M. & Heymann, S. How to Track Adaptation to Climate Change: A Typology of Approaches for National-Level Application. *Ecol. Soc.* **18**, (2013).
35. Lesnikowski, A. C., Ford, J. D., Berrang-Ford, L., Barrera, M. & Heymann, J. How are we adapting to climate change? A global assessment. *Mitig. Adapt. Strateg. Glob. Change* **20**, 277–293 (2015).
36. Smit, B. & Wandel, J. Adaptation, adaptive capacity and vulnerability. *Glob. Environ. Change* **16**, 282–292 (2006).
37. Silva Villanueva, P. *Learning to ADAPT: monitoring and evaluation approaches in climate change adaptation and disaster risk reduction – challenges, gaps and ways forward.* (2010).
38. Brandt, L. *et al.* A framework for adapting urban forests to climate change. *Environ. Sci. Policy* **66**, 393–402 (2016).
39. U.S. Environmental Protection Agency. *Evaluating Urban Resilience to Climate Change: A Multi-Sector Approach (Final Report).* (2017).

40. U.S. Environmental Protection Agency. Using Trees and Vegetation to Reduce Heat Islands. Available at: <https://www.epa.gov/heat-islands/using-trees-and-vegetation-reduce-heat-islands>. (Accessed: 23rd March 2017)
41. California Environmental Protection Agency. Understanding the Urban Heat Island Index. Available at: <https://www.calepa.ca.gov/climate/urban-heat-island-index-for-california/understanding-the-urban-heat-island-index/>. (Accessed: 23rd March 2017)
42. Torresan, L. Z. USGS Coastal Storm Modeling System, CoSMoS. Available at: [https://walrus.wr.usgs.gov/coastal\\_processes/cosmos/index.html](https://walrus.wr.usgs.gov/coastal_processes/cosmos/index.html). (Accessed: 17th July 2017)
43. Cal-Adapt. Sea Level Rise: Threatened Areas Map. *Cal-Adapt* (2014). Available at: <http://cal-adapt.org/sealevel/>.
44. U.S. Environmental Protection Agency. Build Resilience at Your Utility. Available at: <https://www.epa.gov/crwu/build-resilience-your-utility>. (Accessed: 23rd March 2017)
45. California Department of Water Resources. *Climate Change Handbook for Regional Water Planning*. (2011).
46. U.S. Environmental Protection Agency. *Flood Resilience Checklist*. (2014).
47. California Department of Food and Agriculture. *Healthy Soils Action Plan*. (California Department of Food and Agriculture, California Environmental Protection Agency, California Natural Resources Agency, 2016).
48. California Department of Water Resources. *A Proposed Methodology for Quantifying the Efficiency of Agricultural Water Use*. (Division of Statewide Integrated Water Management, Water Use and Efficiency Branch, 2012).
49. Habitat Quantification Tool. *Environmental Defense Fund* Available at: <https://www.edf.org/ecosystems/habitat-quantification-tool>. (Accessed: 23rd March 2017)

50. California Essential Habitat Connectivity Project. Available at:  
<https://www.wildlife.ca.gov/conservation/planning/connectivity/CEHC>. (Accessed: 23rd March 2017)
51. Areas of Conservation Emphasis (ACE-II). Available at:  
<https://www.wildlife.ca.gov/Data/Analysis/Ace>. (Accessed: 23rd March 2017)
52. Blue Earth Consultants, LLC. *California State Wildlife Action Plan: Implementation Evaluation 2005-2014*. (California Department of Fish and Wildlife, 2015).
53. Cal-Adapt. Wildfire: Fire Risk Map. *Cal-Adapt* (2008). Available at: <http://cal-adapt.org/fire/>.