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Does infill outperform climate-adaptive growth policies in meeting sustainable urbanization goals? A scenario-based study in California, USA

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HIGHLIGHTS

- Demonstrates integration of climate impacts and urban growth for a large area.
- Informs strategic regional planning for new urban growth.
- Responds to calls in the literature to advance beyond general impact projections to strategy-informing research.

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ABSTRACT

Land allocation for urban growth is central to sustainable development strategy because urban growth can impact space available for food production, ecosystem services and biodiversity conservation. Urbanization is a growing stressor due the 2.5 billion additional people projected to live in urban areas by 2050. Potential climate change impacts to natural systems increase the need for sustainable urbanization, which should integrate land use needs for urban growth with climate adaptation objectives such as maintaining biodiversity, food production and ecosystem services. Here we compare climate-neutral and climate-adaptive urbanization scenarios to see which produces the most sustainable urbanization, defined as being the most effective at meeting development, conservation, and two climate adaptation objectives. We modeled five urban growth scenarios portraying an increase of 25.8 million people by 2050 for California, USA comprising three climate-neutral scenarios: business-as-usual, compact-new-growth and infill (redevelopment); and two climate-adaptive scenarios: preservation of agricultural climate refugia or future plant dispersal corridors. Infill was the least impacting for the multiple objectives tested; preserving 46–57% more land for other uses. Each climate-adaptive scenario reduced land consumption for its respective target, but increased impacts to the opposite climate-adaptive scenario target. Infill has the potential to contribute towards sustainable urbanization, particularly if combined with other climate adaptation targets.

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1. Introduction

Urbanization is an important factor in achieving sustainable development (Wu, 2014) because over 54% of the global population is in cities and urban environments. Since 2008 most humans experience urban environments as the new normal and cities are expanding at a rapid rate, with an additional 2.5 billion peo-

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ple projected to live in them by 2050 (United Nations, 2014). A major challenge to make urbanization sustainable is to understand the trade-off between allocating land for future urban areas and the opportunity costs of such land consumption on existing ecosystems. Urban growth impacts land available for agriculture (Lambin & Meyfroidt, 2011), livestock production (Satterthwaite, McGranahan, & Tacoli, 2010), timber (Nowak & Walton, 2005), biodiversity (Grimm, Faeth et al., 2008; Grimm, Foster et al., 2008; Newbold et al., 2015; Seto, Gunerlap, & Hutyra, 2012), and ecosystem services such as water delivery and carbon sequestration (Grimm et al., 2008a,b; Hutyra, Yoon, & Alberti, 2011; Theobald, Hobbs, Bearly, Zack, Shenk, & Riebsame, 2000). However, land allocation for urban growth should also consider the stress that climate change may impose on regional ecosystems and the services they provide. Climate change may fundamentally alter the spatial patterns of land needed for a variety of objectives. For example, climatically suitable environments for native species may shift from one area to another (Brooker, Travis, Clark, & Dytham, 2007), food production areas may be more or less vulnerable to climate change (Schmidhuber & Tubiello, 2007), and risks from fire and other disturbances may become more pronounced (Moritz et al., 2012). Therefore, we expect that the careful coupling of climate change effects in surrounding ecosystems with projected urban growth models can yield more sustainable urbanization opportunities, i.e. future urbanization that minimizes consumption of existing and potential future ecosystem lands at regional scales.

To determine whether climate-adaptive urban growth scenarios outperform climate-neutral, or conventional, urban growth scenarios to achieve sustainable urbanization, we used UPlan, a high-resolution, spatially explicit gridded urban growth model (Johnston, Shabazian, & Gao, 2003) whose input parameters can be manipulated to represent different policy scenarios (Thorne, Santos, & Bjorkman, 2013). We modeled five policy scenarios: three are conventional urban development approaches that do not consider climate impacts (Business-as-Usual, Compact-New-Growth, Infill); and two others target climate adaptation by preventing new urban development on agricultural land projected to be least impacted from climate change, or on lands identified as the most critical climate corridors required for 2235 plant species native to California to reach future climate-suitable locations (Thorne, Bjorkman, & Roth, 2012; Hannah, Shaw, Roehrdanz, Ikegami, Soong, & Thorne, 2012). Climate projections were used to identify the most important aggregate pathways for plant dispersal to future climatically suitable areas (Hannah et al., 2012; Phillips, Williams, Midgely, & Archer, 2008). For the Agricultural Adaptation scenario, we ranked agricultural lands from most to least climatically exposed, and assigned a range of urban growth attractor and detractor values to move new urban growth towards agricultural lands expected to be most impacted by climate change, and minimize new growth on the least climatically impacted agricultural lands. For the Biodiversity Adaptation scenario, we similarly discouraged new growth from occurring in corridors needed by the most plant species for dispersal to future climatically suitable locations, and attracted new urban growth elsewhere.

We used California, USA as a model system. California covers 410,000 km^2, and is expected to grow to 50–60 million inhabitants by 2049 from 33.5 million in 2000, the base year for our urban growth modeling (Sanstad, Johnson, Goldstein, & Franco, 2009; State of California, 2012). In 2000, the state had 21,230 km^2 in urban extent containing 81.3% of the state's population (State of California, 2012). By 2010 the urban area has increased by 1.4% (United States Census, 2010). The projected 50-year time frame represents the outer horizon for which state and county planning typically occurs in California. We used the higher population growth projection and the more impacting of two climate projections tested in order to have a clear picture over the potentially conflicting land-use needs. We used a population growth projection of ~25.8 × 10^6 by 2050 (Sanstad et al., 2009), and two climate projections representing annual minimum temperature warming of 1.1–1.8 °C and changes in annual precipitation of +8- −5% by 2050, from base statewide mean climate values of 6.9 °C and 587.1 mm during 1981–2010 (Thorne et al., 2012; Flint, Flint, Thorne, & Boynton, 2012; Thorne, Boynton, Flint, & Flint, 2015). Climate data at 270 m grid scale were used to rank California's agricultural areas (Hollander, 2010) from least to most aggregate climate exposure. We sought the scenario that accommodates new population growth with the least impact on the area of existing natural vegetation, future native plant climate corridors, and agricultural climate refugia as the best (and most sustainable) urbanization solution.

2. Methods

We developed five urban growth scenarios for the projected 25.8 million new California residents by 2050 (Sanstad et al., 2009), and ran projections of the spatial location of the needed urban growth using UPlan (Johnston et al., 2003; Beardsley, Thorne, Roth, & McCoy, 2009; Thorne et al., 2013), an urban growth model with high spatial resolution. Three scenarios are urban growth policy–only and do not incorporate climate adaptation, because we wanted to test whether by such policies alone we could meet goals for both development and climate adaptation, or if additional action would be required for climate adaptation:

1 Business-As-Usual (BAU) that simulates legally permissible urban sprawl;
2 Compact-New-Growth (CNG) that increases the density of new growth and situates it closer to existing urban centers;
3 Infill (IF) a redevelopment scenario that places a proportion of new growth inside existing urban boundaries (Thorne et al., 2012, 2013).

We created two new climate adaptation scenarios that incorporate climate risk:

1 Biodiversity Adaptation (BA) that minimizes new urban expansion on lands projected as needed for large numbers of plant species to disperse from current ranges to new ranges;
2 Agricultural Adaptation (AA) that minimizes impacts to existing agricultural lands that are expected to be those least impacted by changing climate.

Each scenario was run from 2000 to 2050 on a per-county basis for the 58 counties in California, and the results aggregated to statewide scale (Thorne et al., 2012).

2.1. Urban growth model – UPlan

UPlan is a rule-based, spatially explicit model that assigns new urban growth based on a combination of population projections, existing infrastructure, and a series of spatial attractors and discouragement factors. The UPlan model can be used to project and compare future development patterns from different land use policies, and is typically run for individual counties. The UPlan model requires relatively few parameters, and is therefore useful for scenario visualization (Beardsley et al., 2009; Huber, Thorne, Roth, & McCoy, 2011; Roth, Thorne, Johnston, & McCoy, 2012; Byrd, Rissman, & Merenlender, 2009). Actual patterns of development are affected by many things outside of policy. The goal of this tool is not to replicate exact patterns of development, but to estimate the mag-

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