# Supplementary Material: Ecosystem carbon balance in the Hawaiian Islands under different scenarios of future climate and land use change

August 09, 2021

## Moisture Zones

Agriculture, Forest, Grassland, Shrubland, and Tree Plantation land cover classes were stratified into three Moisture Zones - Dry, Mesic, and Wet (supplemental Figure 1). These three zones were based on a moisture availability index (MAI), calculated as mean annual precipitation (MAP) minus potential evapotranspiration (PET; Price *et al* 2012). Areas where where MAI values were less than zero (i.e., where MAP < PET) were classified in the Dry Moisture Zone. Areas with MAI values between zero and 1,661 were classified in the Mesic Moisture Zone. The MAI value of 1,661 is roughly equivalent to areas at 1,000 m elevation that receive 2,500 mm of annual rainfall (Price *et al* 2012). Areas with MAI values greater than 1,661 were classified in the Wet Moisture Zone.

## Wildland Fire

We used a new spatial database of wildland fire perimeters on the main Hawaiian Islands from 1999-2019 to calculate annual area burned (supplemental Figure 2), wildland fire probabilities by state type, and wildland fire size distributions. This new database compiles prior mapping efforts and data collections with newly mapped fire perimeter data from Dr. Clay Trauernicht (Department of Natural Resources and Environmental Management, University of Hawai‘i at Mānoa). The goal was to locate and map all fires greater than or equal to 20 hectares, but some smaller fires were included as detected in imagery. Fire perimeters for the years 2002-2011 were primarily from the U.S. Geological Survey’s Monitoring Trends in Burn Severity (MTBS; https://www.mtbs.gov). The Hawaii Wildfire Management Organization (www.hawaiiwildfire.org) provided ground-based, GPS-mapped fire perimeters from Hawai‘i Island, mostly from the Kona and Kohala regions. The

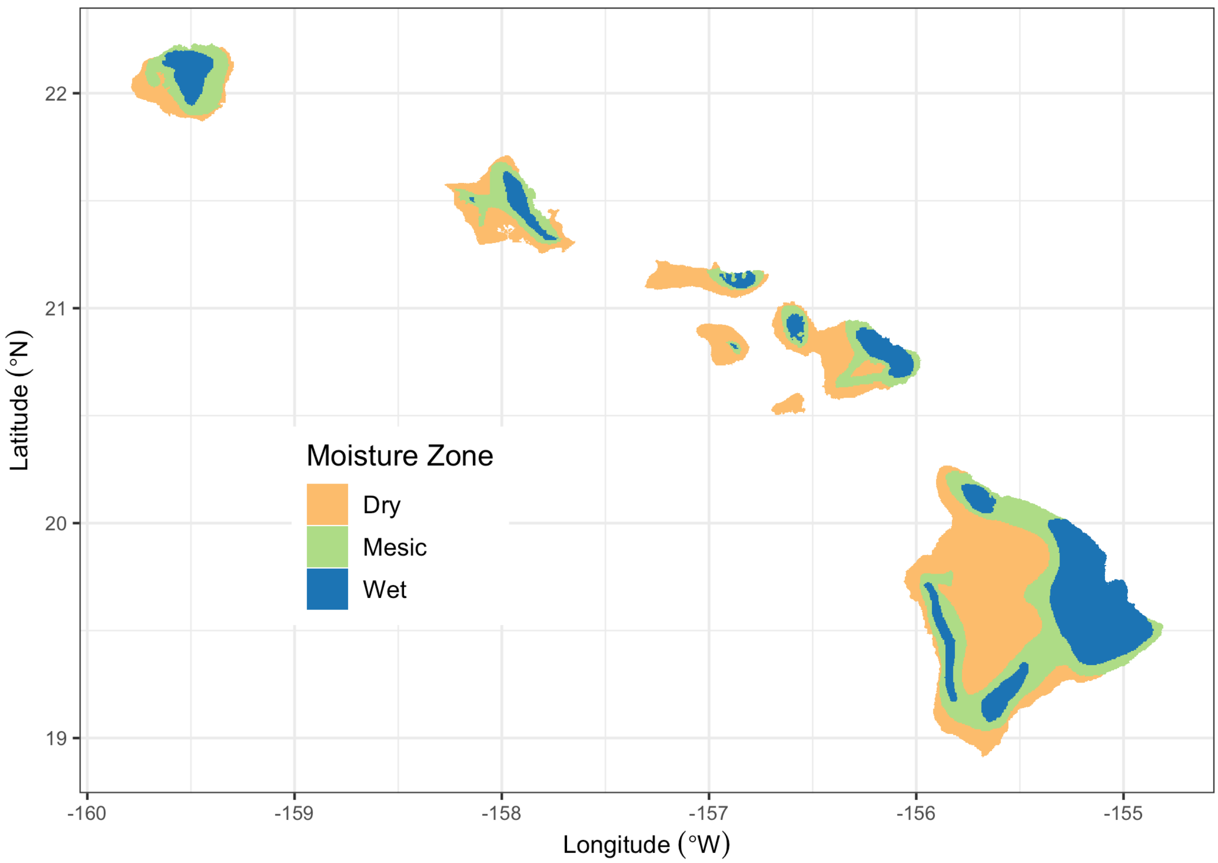


Figure 1: Supplemental - Moisture zones of the seven main Hawaiian Islands, adapted from Jacobi *et al.* (2017).

U.S. National Park Service provided ground-based, GPS-mapped fire records from Hawai‘i Volcanoes National Park. The O‘ahu Army Natural Resource Program provided ground-based, GPS-mapped fire records on O‘ahu. All other fires were mapped directly by Dr. Trauernicht using LANDSAT and Sentinel-2 satellite imagery. Data from USGS MTBS were prioritized for the years 2002-2011 in the case of duplicate records.

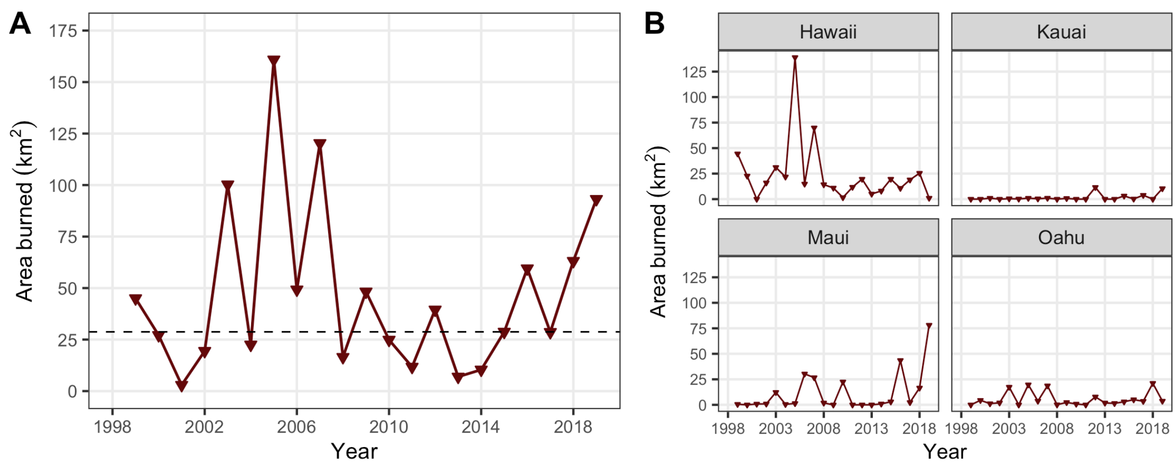


Figure 2: Supplemental - Annual area burned by wildland fire in the State of Hawai‘i from 1999-2019, summed by year across the seven main Hawaiian Islands (A) and within each of the four largest islands (B). The dashed horizontal line in (A) represents the median area burned from 1999-2019.

## Climate

Spatially explicit contemporary mean annual temperature and rainfall data for the main Hawaiian Islands at 250-m resolution (supplemental Figure 3) are from Giambelluca *et al* (2013) and Giambelluca *et al* (2014). Spatially explicit projections of change in annual temperature and annual rainfall for mid-century (2049-2069) and end of century (2070-2099; supplemental Figure 4) are from statistically downscaled CMIP5 climate projections under RCP 4.5 and RCP 8.5 from Elison Timm *et al* (2015) and Elison Timm (2017). To avoid biases, the modeled present-day (1975–2005) CMIP5 climatology was used to standardize the resulting predictor time series, and the simulated future changes were measured relative to their present-day mean states. See Elison Timm *et al* (2015) and Elison Timm (2017) for a more detailed description of potential statistical downscaling biases.

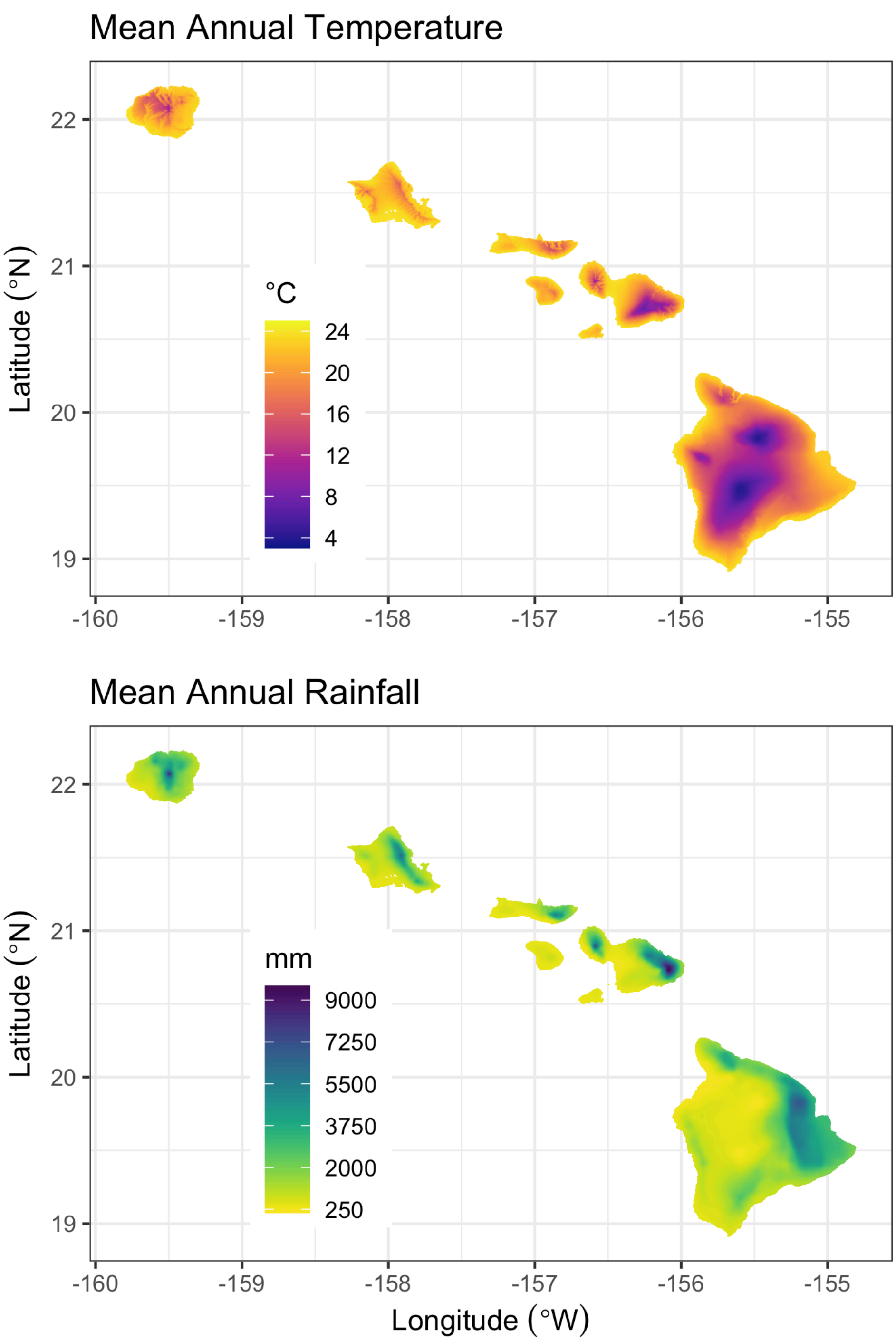


Figure 3: Supplemental - Contemporary 30-year climate normals for mean annual temperature (top panel) and mean annual rainfall (bottom panel) for the seven main Hawaiian Islands. Data from Giambelluca *et al.* (2013) and Giambelluca *et al.* (2014).

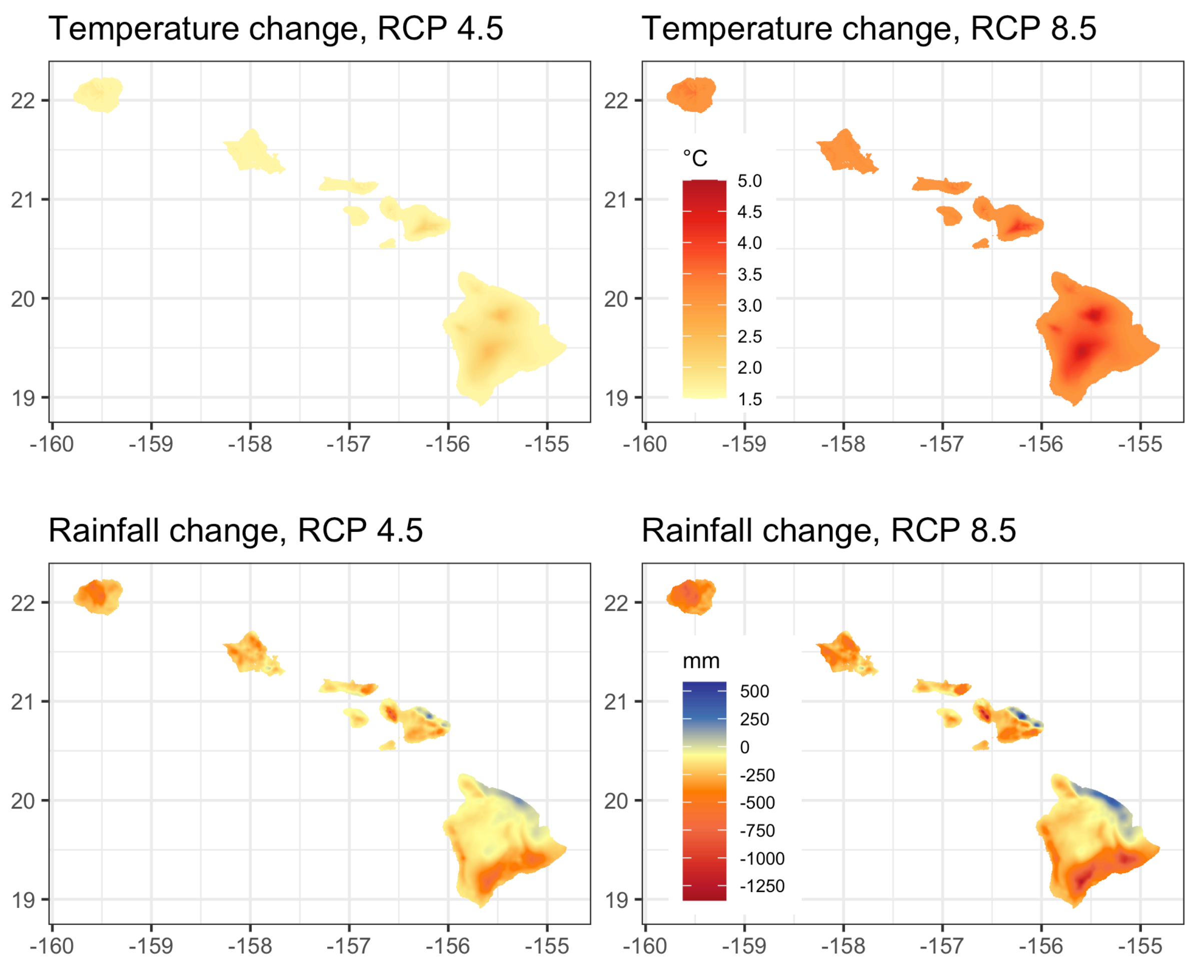


Figure 4: Supplemental - Projected change in mean annual temperature (top panels) and mean annual rainfall (bottom panels) by 2100 under RCP 4.5 and RCP 8.5 based on statistical downscaling of an ensemble of climate models (CMIP5).

Table 1: Supplemental - Mean IBIS-derived NPP values by Land Cover and Moisture Zone, in kg of C per square meter per year.

| | NPP by Moisture Zone | | |
|---|---|---|---|
| Land.Cover | Dry | Mesic | Wet |
| Agriculture | 0.34 | 0.32 | 0.30 |
| Forest | 0.29 | 0.84 | 1.14 |
| Grassland | 0.21 | 0.47 | 0.81 |
| Tree Plantation | 0.29 | 0.84 | 1.14 |
| Shrubland | 0.31 | 0.55 | 0.85 |
| Woody Crop | 0.21 | 0.67 | 0.56 |

**Initializing NPP**

Initial values for net primary production (NPP) in LUCAS were calculated using a lookup table derived from the Integrated Biosphere Simulator (IBIS; supplemental Table 1). These values were adjusted with spatially explicit stationary NPP multipliers to reflect local variation driven by microclimate (supplemental Figure 4) as described in detail in Sleeter *et al* (2018) and Sleeter *et al* (2019). Briefly, we derived the set of NPP spatial multipliers by first calculating NPP independently of the IBIS values for each simulation cell using empirical relationships between total annual NPP and mean annual rainfall or temperature (Schuur 2003, Del Grosso *et al* 2008) based on Hawai‘i-specific climate data (supplemental Figure 3; Giambelluca *et al* (2013); Giambelluca *et al* (2014)). We then calculated the NPP spatial multipliers as the NPP anomaly for each simulation cell relative to the mean of these empirically-derived NPP values for each state type (i.e., the unique combination of moisture zone and land cover class; supplemental Figure 4). These NPP multipliers were then applied to the IBIS-derived values to create a spatial distribution of NPP used to initiate the LUCAS model (supplemental Figure 4).

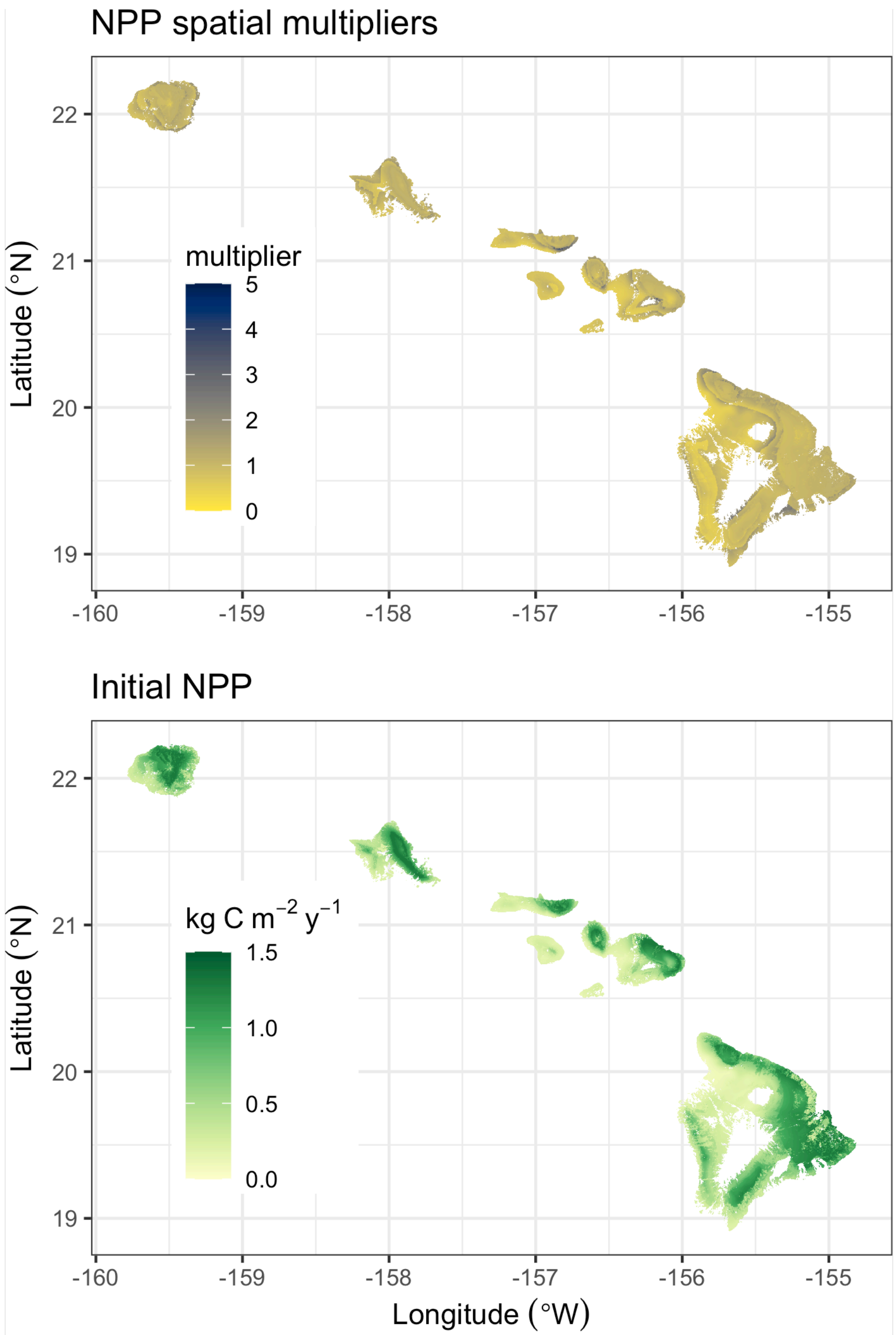


Figure 5: Supplemental - Stationary spatial NPP multipliers (top panel) and initial NPP based on the product of mean IBIS-derived NPP values (supplemental Table 1) and stationary spatial NPP multipliers (above). Developed and Barren land cover types are excluded from both maps.

## Change in State Class Area

Projections of total land area covered by each of five State Classes (Agriculture, Developed, Forest, Grassland and Shrubland) were summed by year and Monte Carlo iteration across the seven main Hawaiian Islands for each of two land use scenarios (low and high; Figure S5).

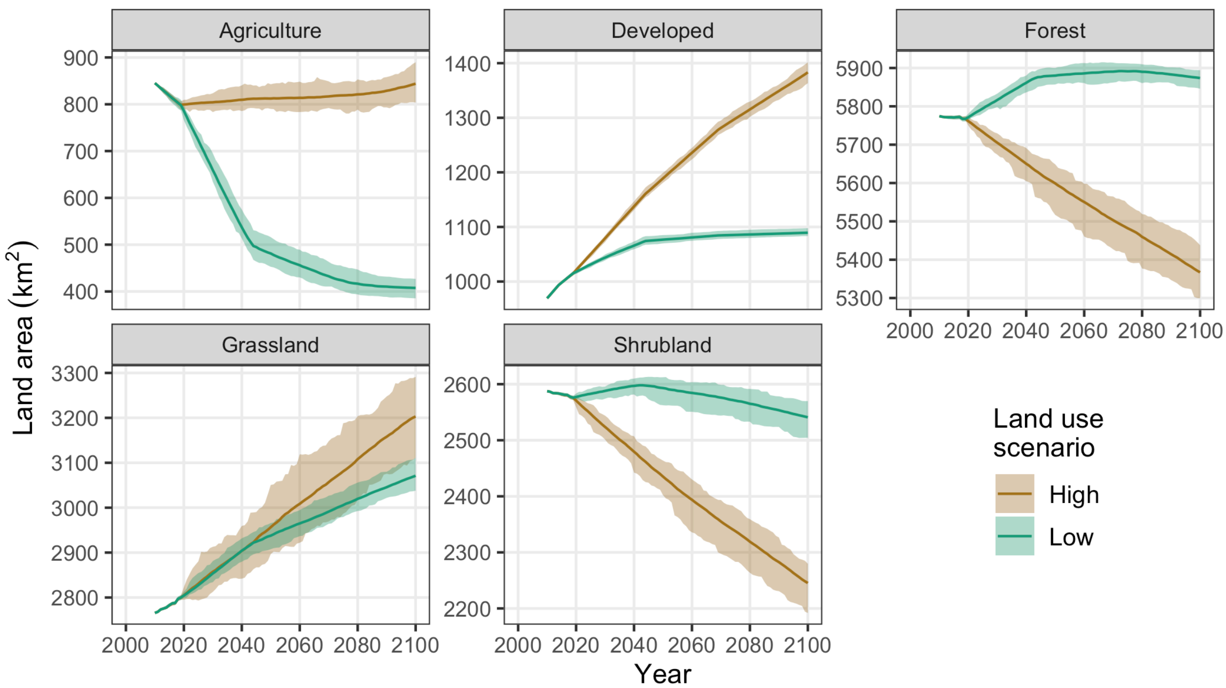


Figure 6: Supplemental - Projections of total land area by year for each of five State Classes in the seven main Hawaiian Islands (Agriculture, Developed, Forest, Grassland, and Shrubland) under low and high land use change scenarios for the period 2010-2100. Solid lines represent the mean of 30 Monte Carlo realizations and shaded areas represent minimum and maximum Monte Carlo values.

## References


Del Grosso S, Parton W, Stohlgren T, Zheng D, Bachelet D, Prince S, Hibbard K and Olson R 2008 Global potential net primary production predicted from vegetation class, precipitation, and temperature *Ecology* **89** 2117–26

Elison Timm O 2017 Future warming rates over the Hawaiian Islands based on elevation-dependent scaling factors *International Journal of Climatology* **37** 1093–104 Online: https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/joc.5065

Elison Timm O, Giambelluca T W and Diaz H F 2015 Statistical downscaling of rainfall changes in Hawai‘i based on the CMIP5 global model projections *Journal of Geophysical Research: Atmospheres* **120** 92–112

Giambelluca T W, Chen Q, Frazier A G, Price J P, Chen Y-L, Chu P-S, Eischeid J K and Delparte D M 2013 Online Rainfall Atlas of Hawai‘i *Bull. Amer. Meteor. Soc.* **94** 313–6

Giambelluca T W, Shuai X, Barnes M L, Alliss R J, Longman R J, Miura T, Chen Q, Frazier A G, Mudd R G, Cuo L and Businger A D 2014 *Evapotranspiration of Hawai‘i* Online: http://evapotranspiration.geography.hawaii.edu/downloads.html

Jacobi J, Price J, Gon III S and Berkowitz P 2017 Hawaii Land Cover and Habitat Status: U.S. Geological Survey data release Online: https://doi.org/10.5066/F7DB80B9

Price J, Jacobi J, Gon III S, Matsuwaki D, Mehrhoff L, Wagner W, Lucas M and Rowe B 2012 *Mapping plant species ranges in the Hawaiian Islands - developing a methodology and associated GIS layers* (U.S. Geological Survey) Online: https://pubs.usgs.gov/of/2012/1192/

Schuur E A 2003 Productivity and global climate revisited: The sensitivity of tropical forest growth to precipitation *Ecology* **84** 1165–70

Sleeter B M, Liu J, Daniel C, Rayfield B, Sherba J, Hawbaker T J, Zhiliang Zhu, Selmants P C and Loveland T R 2018 Effects of contemporary land-use and land-cover change on the carbon balance of terrestrial ecosystems in the United States *Environ. Res. Lett.* **13** 045006 Online: http://stacks.iop.org/1748-9326/13/i=4/a=045006

Sleeter B M, Marvin D C, Cameron D R, Selmants P C, Westerling A L, Kreitler J, Daniel C J, Liu J and Wilson T S 2019 Effects of 21st-century climate, land use, and disturbances on ecosystem carbon balance in California *Global Change Biology* **25** 3334–53