

1 Ecosystem carbon balance in the Hawaiian Islands under
2 different scenarios of future climate and land use change

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4 Paul C. Selman^{1,6}, Benjamin M. Sleeter², Jinxun Liu¹, Tamara S. Wilson¹,
5 Parker C. Trauernicht³, Abby G. Frazier⁴, Gregory P. Asner⁵

6 **Affiliations:**

7 ¹U.S. Geological Survey, Moffett Field, CA, USA

8 ²U.S. Geological Survey, Seattle, WA, USA

9 ³University of Hawai'i at Mānoa, Honolulu, HI, USA

10 ⁴The East-West Center, Honolulu, HI, USA

11 ⁵Arizona State University, Tempe, AZ, USA

12 ⁶Author to whom correspondence should be addressed

13 **Email:** pselmants@usgs.gov

14 **Running title:** Hawaii carbon balance

15 **Keywords:** land use, climate change, carbon balance, Hawaii, scenarios, disturbance, ecosys-
16 tem model

17 **Date:** July 31, 2020

Abstract

The State of Hawai'i passed legislation in 2018 setting a goal to be carbon neutral by 2045. Meeting this goal will partly depend on carbon sequestration by terrestrial ecosystems, yet the future direction and magnitude of the land carbon sink in the Hawaiian Islands is highly uncertain. We used simulation modeling to assess how projected future changes in climate and land use will influence ecosystem carbon balance in the Hawaiian Islands under four unique scenarios over a 90-year timespan. Net ecosystem carbon balance declined under all four scenarios. Moving from a high to a low radiative forcing scenario reduced net ecosystem carbon loss by $\sim 21\%$, and net carbon losses were reduced by a total of $\sim 55\%$ under the combined scenario of low radiative forcing and low rates of land-use change. A sensitivity test of the CO_2 fertilization effect on plant productivity revealed it to be a major source of uncertainty in projections of ecosystem carbon balance. Reconciling this uncertainty in how net photosynthesis will respond to rising atmospheric CO_2 will be essential to better constraint of models used to evaluate the effectiveness of ecosystem-based climate mitigation strategies.

Introduction

Methods

We used the Land Use and Carbon Scenario Simulator (LUCAS), an integrated landscape change and carbon gain-loss model, to project changes in ecosystem carbon balance for the seven main Hawaiian Islands under four scenarios of climate and land-use change. The landscape change portion of LUCAS is a state-and-transition model that applies a Monte Carlo approach to track the state type and age of each simulation cell in response to a pre-determined set of transitions (Daniel *et al* 2016). The carbon gain-loss portion tracks carbon stocks within each simulation cell over time as continuous state variables, along with a pre-

defined set of continuous flows specifying stock level rates of change over time (Daniel *et al* 2018, Sleeter *et al* 2019). We parameterized the Hawai'i LUCAS model to estimate annual changes in carbon stocks and fluxes in response to land use, land use change, wildland fire, and long-term climate variability. Simulations were run for 90 years at an annual timestep, using initial conditions corresponding to the year 2010. All simulations were repeated for 30 Monte Carlo realizations.

Study area

The spatial extent of this study was the terrestrial portion of the seven main Hawaiian Islands (Figure 1), a total land area of 16,554 km². We subdivided this landscape into a grid of 264,870 simulation cells, each of which was 250 x 250 m in size. Each simulation cell was assigned to one of 210 possible state types based on the unique combination of three moisture zones (dry, mesic, and wet; Figure S1), seven islands, and ten discrete land cover classes (Figure 1).

States and transitions

We developed a high and a low land-use scenario, with transition pathways modified from Daniel *et al* (2016). Transitions between state types were pre-defined to represent urbanization, agricultural contraction, agricultural expansion, harvesting of tree plantations, and wildfire. Agriculture, forest, grassland, tree plantation, and shrubland state types each had multiple transition pathways, while the barren state type could only transition to urban. Although several state types had urbanization transition pathways, there was no transition pathway from urban to any other state type. Water and wetland state types remained static throughout the simulation period.

Transition targets were based on historical trends of land use change and population projections. For the high land-use scenario, rates of agricultural contraction, agricultural expansion,

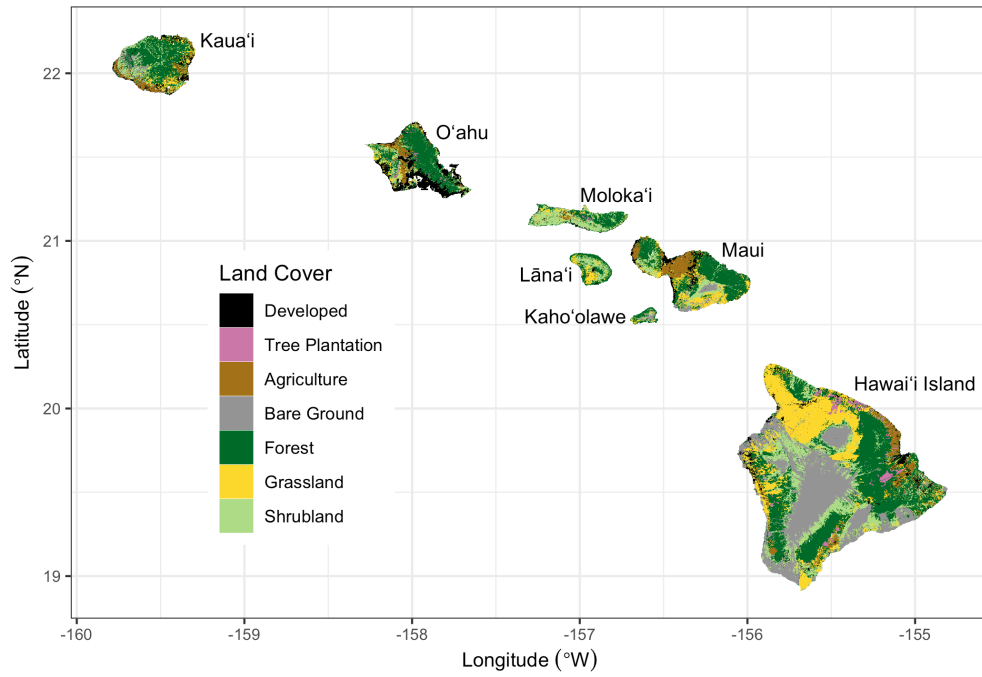


Figure 1: Land cover classification of the seven main Hawaiian Islands, adapted from Jacobi et al (2017). Agriculture in this map combines herbaceous and woody crops, but these two crop types are treated as separate land cover classes in the simulation model. Water and Wetland land cover classes are not shown.

and urbanization were derived from remote sensing-based time series maps of land use change in the Hawaiian Islands from 1992-2011 developed by the National Oceanic and Atmospheric Administration Office of Coastal Planning (NOAA 2020). We sampled transition rates for each timestep and Monte Carlo realization from uniform distributions bounded by the median and maximum historical values of agricultural contraction, agricultural expansion, and urbanization for each island. For the low land-use scenario, rates of agricultural contraction and expansion were derived from the same NOAA time series by sampling from uniform distributions bounded by zero and the minimum historical values for each island. Urbanization rates in the low land-use scenario were based on island-level population estimates and projections at five year intervals from 2010-2045 (Kim and Bai 2018). We converted population projections into urbanization transition targets following Sleeter *et al* (2017) by calculating population density for each island and then projecting future developed area based on the five-year incremental change in island population. The spatial extent of agricultural contraction, agricultural expansion, and urbanization was constrained in both land-use scenarios based on existing zoning maps (Daniel *et al* 2016).

The wildfire transition sub-model was modified from Daniel *et al* (2016) using a new wildfire spatial database for the Hawaiian Islands from 1999-2019 (Figure S4). Wildfire size distribution and ignition probabilities for each year were calculated from this 21-year time series for each unique combination of moisture zone (Figure S1), island, and state type (Figure 1). The number and size of fires was randomly drawn from one of these historical year-sets for each timestep and Monte Carlo realization, using burn severity probabilities from Selman *et al* (2017). Wildfire in the low land-use scenario was sampled from the subset of historical fire years at or below the 21-year median area burned statewide and the high land-use scenario sampled from historical fire years above this 21-year median (Fig. S4a).

Tree plantation harvesting

91 *Carbon stocks and flows*

92 *Initial conditions*

93 *Scenario simulations*

94 **Results**

95 **Discussion**

96 **Conclusion**

97 **Acknowledgements**

98 This study was funded by the Biological Sequestration Program of the U.S. Geological Survey.
99 Thanks to Nicholas Koch of Forest Solutions, Inc. for information on eucalyptus harvesting
100 and to Leonardo Frid and Colin Daniel of ApexRMS for assistance with the SyncroSim
101 software. Any use of trade, firm, or product names is for descriptive purposes only and does
102 not imply endorsement by the U.S. Government.

103 **Data Availability**

104 Tabular model output data are available from the USGS ScienceBase data repository at:
105 <https://doi.org/10.5066/P9AWLFKZ>. Model input data and R code used to format input
106 data, summarize output data, and compile this manuscript are available from the HI_Model
107 GitHub repository at: https://github.com/selmants/HI_Model.

ORCID

Paul C. Selman <https://orcid.org/0000-0001-6211-3957>

Benjamin M. Sleeter <https://orcid.org/0000-0003-2371-9571>

Jinxun Liu <https://orcid.org/0000-0003-0561-8988>

Tamara S. Wilson <https://orcid.org/0000-0001-7399-7532>

Abby G. Frazier <https://orcid.org/0000-0003-4076-4577>

Gregory P. Asner <https://orcid.org/0000-0001-7893-6421>

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