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Deforestation poses deleterious effects to tree-climbing species under climate change

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Abstract

Habitat loss poses a major threat to global biodiversity. Many studies have explored the potential damages of deforestation to animal populations but few have considered trees as thermoregulatory microhabitats or addressed how tree loss might impact the fate of species under climate change. Using a biophysical approach, we explore how tree loss might affect semi-arboreal diurnal ectotherms (lizards) under current and projected climates. We find that tree loss can reduce lizard population growth by curtailing activity time and length of the activity season. Although climate change can generally promote population growth for lizards, deforestation can reverse these positive effects for 66% of simulated populations and further accelerate population declines for another 18%. Our research underscores the mechanistic link between tree availability and population survival and growth, thus advocating for forest conservation and the integration of biophysical modelling and microhabitat diversity into conservation strategies, particularly in the face of climate change.

Data availability

The microclimates on the ground are available in ref. [29]. Owing to its substantial size, the microclimate dataset of tree trunks is not available on a publicly accessible server. However, the data are available upon request. All model output data, including all the data needed for creating the figures and tables, are available from Zenodo at https://doi.org/10.5281/zenodo.10546868 (ref. [55]).

Code availability

The original trunk temperature model, lizard model and all codes for data analysis and figure creation are available with the data from Zenodo[55]. Updates to the codebase are available at https://github.com/levyofi/Zlotnick_et_al_NCLIM_2024.

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O.B.Z. performed research and analysed data. O.L. designed research and provided mentorship. O.B.Z. and O.L. wrote the first version of the article. K.N.M. contributed new reagents/analytic tool. All authors contributed to writing of the final article.

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Ethics declarations

Competing interests

The authors declare no competing interests.

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Extended data

Extended Data Fig. 1 A scheme of the microhabitats available for a simulated lizard.

The availability of microhabitats differed between our two deforestation scenarios (with or without available trees). In the scenario with available trees, the lizard can exploit all the potential microhabitats in all postures (56 combinations of microhabitat, shade level, and posture). Under the scenario of tree loss, it can exploit only the microhabitats on the ground (4 combinations). This scheme applies only to daytime; at night, the lizard is limited to lying on the ground in 100% shade or entering a burrow.

Extended Data Fig. 2 Proportion of time spent on sunlit tree trunks.

The predicted proportion of time spent on sunlit tree trunks when climbing was necessary for activity under current climate (1980–2000). Lizards predominantly climb on sunlit tree trunks rather than shaded ones, except in the warmest locations. The time of necessary climbing was defined as periods when the tree trunk was the only microhabitat enabling the lizard to reach its body temperature within the activity temperature range. Climbing on sunlit tree trunks showed a high correlation with basking behaviour, particularly when other microhabitats were too cold for activity. This suggests that lizards primarily use tree trunks as a warm retreat during colder periods of the year or day.

Extended Data Fig. 3 A typical summer day for a simulated lizard.

During mornings and evenings, lizards primarily used sunlit tree trunks, while shaded tree trunks were favoured during midday. The plots depict the lizard's predicted thermoregulatory behaviour in three different climates: (**a**) New Jersey, with a seasonal climate; (**b**) Colorado, with a cool climate; and (**c**) Arizona, with a warm climate. In Colorado's cool climate, lizards predominantly used sunlit tree trunks throughout the day. The values represent the average time spent in each micro-environment per hour, aggregated across all summer days (June-August) from 1980 to 2000.

Extended Data Fig. 4 Climbing height and the thermal benefit for lizards.
Lizards climb higher when they need to cool down and lower when they need to warm up. The represented data considers only 'necessary climbing', which occurs when lizards must climb to maintain their body temperature within the desired activity range. The colour of each hexagon represents the average air temperature of locations sharing the same x and y values.

Extended Data Fig. 5 The effect of tree loss on the annual activity time of lizards.
Across the climatic gradient, tree loss is projected to significantly reduce lizards' activity time. Cooler locations are expected to show a greater relative reduction, while warmer locations may experience a more substantial absolute reduction. The panels illustrate: (**a**) Mean annual activity hours from 1980 to 2000 when lizards are able to climb trees; (**b**) Mean absolute decrease in annual activity hours from 1980 to 2000 due to tree loss; and (**c**) Mean relative decrease in annual activity hours attributable to tree loss. Mean annual activity hours were calculated by summing all active time units over the 20-year period, then dividing by 60 (to convert minutes to hours) and by 20 to determine the average yearly activity.

Extended Data Fig. 6 The effect of tree loss on the annual growth rate of lizard populations.
Tree loss is expected to reduce the annual growth rate of lizard populations across the entire climatic gradient, with a greater absolute decrease in warmer locations and a

more pronounced relative decrease in cooler ones. The presented maps depict: (**a**) the mean annual growth rate when trees are available (no tree loss), (**b**) the absolute changes in mean annual growth rate (lizards/year) resulting from tree loss, and (**c**) the relative change in mean annual growth rate (%) due to tree loss. Additionally, we illustrate the correlation between climatic conditions and the (**d**) absolute (lizards/year) and (**e**) relative (%) changes in mean annual growth rate attributable to tree loss. The patterns revealed by the absolute and relative changes demonstrate opposite trends: while the absolute decrease in annual growth rate is more significant in warmer locations, the relative reduction is more substantial in cooler locations. In maps (D) and (E), the colour of each hexagon indicates the average air temperature of locations sharing the same x and y values.

Extended Data Fig. 7 The cascading effect of tree loss on activity times and populations' growth rates.

Tree loss negatively impacts lizard activity time, leading to declines in population growth rates. In both aspects, warmer locations are predicted to experience a greater absolute reduction, whereas cooler locations will face a more significant relative reduction. The plots illustrate the correlation between tree loss and its effects on (**a**) Absolute changes (lizards/year and hours/year, for growth rates and activity times, respectively) and (**b**) Relative changes (%). The colour of each hexagon indicates the average air temperature of locations with the same x and y coordinates.

Extended Data Fig. 8 Mapping the damaging effect of tree loss under climate change.

The absence of trees is projected to cause most lizard populations to decline, counteracting any potential benefits from climate change. This includes populations currently anticipated to benefit from such changes. The maps illustrate the predicted impact of climate change on lizard mean annual population growth rates, comparing scenarios where (**a**) trees are available to those where (**b**) trees are absent due to deforestation.

Extended Data Fig. 9 Minimal tree availability needed to prevent population declines under climate change.

We calculated the minimum proportion of the lizard population requiring access to trees to maintain a stable growth rate under climate change for each location (refer to Equation. 28). In (**a**) the map displays the minimum percentage of the lizard population needing tree access to avert decline. Grey shades represent areas where deforestation does not alter the impact of climate change: light grey signifies locations with population increases, and dark grey indicates declines, irrespective of deforestation. In (**b**), we demonstrate the correlation between these predictions and the mean temperature of each location, with each hexagon's colour denoting the average air temperature for areas with corresponding x and y coordinates.

Supplementary information

Supplementary Information

Supplementary Figs. 1–10 and Tables 1–9.

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