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The role of microclimate in maintaining species distribution under climate change:
a case study of the northern pika

(気候変動下の生物分布における微気候の重要性：キタナキウサギにおける検証)

Climate change is posing a grave threat to biodiversity around the globe. One of the widespread impacts of climate change is the change in species distributions, which can bring negative consequences to interacting species as well as ecosystem functions and services. It is therefore imperative to understand the drivers of species distribution and predict how it may change over time. Despite the general trend of poleward and upslope shifts in species distributions, a large variation exists around these responses as many species are found persisting at the trailing edge of the distribution, thus lagging behind isothermal shifts. One hypothesis explaining this phenomenon is that heterogenous thermal conditions generated by complex topography enable species to persist locally while the climate changes at larger spatial scales. This perception follows the microrefugia concept, which considers that populations can persist in small habitat patches by using locally available, favorable environmental conditions even under hostile, environmental changes. Therefore, the importance of microclimate, the thermal conditions existing locally and experienced by individuals, is being increasingly recognized for maintaining species distributions under contemporary climate change. However, there are various aspects in its role that are yet to be explored.

First, few studies have assessed distribution changes in species that utilize microclimates, and therefore, the effectiveness of microclimates in maintaining species distribution remains unclear. Second, since previous studies have not assessed the relative importance of microclimate with other drivers of species distribution, the environmental context in which microclimate is important for shaping species distribution remains poorly discussed. Third, despite the development of species distribution predictions that account for microclimates, few studies have validated its accuracy in predicting range shifts over time. In this dissertation, I aimed to assess the role of microclimate in species range dynamics under climate change by conducting a case study on the northern pika (*Ochotona hyperborea*), since thermal buffering effects have been reported in its rocky landform habitats.

In Chapter 2, I aimed to develop a foundation method for surveying the northern pika distribution by assessing the efficacy of aural detection methods. I compared the efficacy of auditory observation, in which naturally occurring vocalizations of pikas are surveyed, and playback, in which acoustic cues are used to trigger vocalizations from pikas. Based on time-wise accuracy, playback was suggested as a highly effective method for surveying site occupancy. Therefore, playback was used to survey the northern pika distribution in this dissertation.

In Chapter 3, I assessed how the northern pika distribution has changed from the past (1961-2010) by

conducting resurveys along a wide elevational gradient (60–2,210 m). The resurvey revealed population turnovers, shifting from past presence to current absence at low- to mid-elevations, suggesting that the Hokkaido regional population of the northern pika is becoming unstable under rising temperatures. Importantly, however, persistence of some local populations was observed in these warmer regions. As habitat size was found positively correlated with persistence, it is plausible that higher environmental heterogeneity in larger habitats, such as variations in thermal conditions, is important for maintaining the northern pika distribution over time.

In Chapter 4, by measuring habitat thermal conditions along a wide elevational gradient (350–2,200 m), I evaluated their relationships with the northern pika occupancy at two nested spatial scales. Analyses showed that rock interstice microclimate was not an important factor at both the whole-distribution and range-edge (i.e., low-elevations) scale. Instead, other factors such as ambient thermal condition and microhabitat availability influenced occupancy at the whole-distribution scale, whereas presence of human land-use was strongly important at the range edge. Although thermal measurements indicated that rock interstices effectively buffered ambient thermal conditions, these results suggest that the refugial effect of microclimates at the trailing edge could be overridden by other environmental factors due to spatial hierarchy. This implies that the environmental context in which the microclimate exists is crucial for species persistence at the trailing edge.

In Chapter 5, I developed a fine-scale distribution model for the northern pika by using downscaled climate data and showed that the predictive performance becomes slightly higher by considering fine-scale conditions. While the fine-scale model was originally developed based on ambient thermal conditions, accounting for rock interstice microclimates increased the predicted habitat suitability distinctively for the low- to mid-elevation areas owing to the thermal buffering effect, which also was observed in future projections. This suggests that the rock interstice microclimate may facilitate persistence if the northern pika could effectively reduce physiological stress from warming temperatures through behavioral thermoregulation.

In Chapter 6, I evaluated the accuracy of fine-scale species distribution models developed in Chapter 5 by comparing the predictions with the observed distribution in Chapters 3 and 4. Interestingly, models incorporating rock interstice microclimate exhibited the highest accuracy in predicting the current distribution of present sites. This suggests that accounting for microclimate in species distribution models provides more realistic predictions than that based on coarse scales or on ambient thermal conditions as it prevented overestimating range shifts.

Taken together, this dissertation provides evidence that complex topographies have the potential to maintain species distributions at the trailing edge under warming trends, but the refugial effect of microclimates is likely context-dependent given the influences of other environmental factors. This reminds the importance to consider the strong relationship between species distribution and spatial scale: microclimate is an environmental condition occurring at relatively small scales, while conditions at larger scales generally exhibit stronger influence on local population dynamics. Therefore, it will be imperative to consider where microclimate fits in the hierarchical structure of various drivers influencing species distribution to understand range dynamics. Nonetheless, this study highlights the importance of considering the contribution of microclimates when predicting future range shifts under climate change to avoid overlooking potential suitable habitats. To enhance its contribution to species persistence under climate change, it is crucial to incorporate the geological and topographical features that underlie and create microclimates into contemporary conservation planning.