LETTER

In order to provide a complete fitness landscape, the habitat range of phototrophs in Yellowstone National Park is being modelled

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ABSTRACT

Based on 439 observations made in geothermal springs in Yellowstone National Park (YNP), Wyoming, a model was developed to determine how much geochemical variation affects the distribution of phototrophic metabolisms. To forecast the distribution of phototrophic metabolism as a function of spring temperature, pH, and total sulphide, Generalised Additive Models (GAMs) were created. Temperature-based GAMs accounted for 38.8% of the variation in the distribution of phototrophic metabolism, while sulfide- and pH-based GAMs accounted for 19.6 and 11.2% of the variation, respectively. These findings imply that temperature is the main factor limiting the spread of phototrophs in YNP out of the measured variables. A greater proportion of the variation in the distribution of phototrophic metabolism was explained by GAMs with more factors, demonstrating additive interactions between the variables. The dataset's highest volatility (53.4%) was best explained by a GAM that integrated temperature and sulphide while introducing the fewest degrees of freedom. We investigated the effect of sulphide and temperature on Dissolved Inorganic Carbon (DIC) absorption rates under both light and dark circumstances in order to confirm the extent to which phototroph distribution reflects restrictions on activity. In acidic, algal-dominated systems, light-driven DIC uptake reduced systematically with rising sulphide concentrations, but was unaffected in alkaline, cyanobacterial-dominated systems. Light-driven DIC uptake was reduced in cultures incubated at temperatures 10°C higher than them in situ temperature in both alkaline and acidic systems. Together, these quantitative findings show that, besides the availability of light, the habitat range of phototrophs in YNP springs is largely determined by the restrictions placed first by temperature and then by sulphide on the activity of these populations that inhabit the habitat range's periphery. These results support the predictions made by GAMs and offer a mathematical framework for converting distributional patterns into fitness landscapes, which can then be used to evaluate the environmental limitations that have shaped this process' evolution throughout Earth history.

Key Words: *Geothermal; Phototrophic; Metabolism; Wyoming; Environmenta l; Predictions*

INTRODUCTION

The diversity of adaptations that have developed over evolutionary time and allowed life to spread into new ecological niches are at least partially responsible for the distribution of species and the roles that they catalyse on Earth today. Both the genetic history of organisms and their current patterns of organismal dispersal contain records of these responses. This is a result of microorganisms' propensity to acquire their ecological qualities through vertical inheritance, a phenomenon that shows a strong correlation between an organism's ecological relatedness and its evolutionary relatedness. Therefore, current patterns in species distribution or metabolic function provide "a window into the past" and can be used to infer historical environmental limitations on the evolution of a certain metabolic function.

These findings can then be used to forecast how populations or metabolic guilds will react to shifting environmental conditions. Key metabolic activities like photosynthesis are assumed to have originated in the early Earth, when there was a great deal of variety in the geochemical makeup of the surroundings. More than 12,000 geothermal features can be found in Yellowstone National Park (YNP), Wyoming, with a wide range in geochemical composition and temperature. These habitats serve as a field laboratory for investigating how guilds of species prefer to occupy specific ecological niches and defining the range of geochemical conditions that that functional guild is tolerant to. Since it is unlikely that a metabolic process would have evolved in an environment that cannot support

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its function today, we believe that information about that process' habitat range can be quantified. It can also shed light on the features of an environment that permitted the process' adaptation to new habitats.

Phototrophy is the process through which plants, algae, and some microorganisms use sun energy to produce energy for the synthesis of intricate chemical compounds. Recent research has shown that phototrophic assemblage distribution over geochemical gradients in Wyoming's YNP exhibits a non-random pattern.

In the geothermal characteristics of YNP, these research qualitatively identified three ecological axes (temperature, pH, and total sulphide) that seem to limit the habitat range of phototrophs. Uncertainty exists on how much each environmental factor, or their combinations, affects the distribution of phototrophic metabolism in YNP. It is also unclear whether the qualitative trends in the distribution of phototrophic metabolism in YNP noted previously are a result of the detrimental effects that temperature, pH, and sulphide have on the activity of phototrophic populations, which would then be expected to decrease fitness and limit their distribution.

Here, we combined environmental metadata and presence/absence distributional data from many independent analyses of phototrophic metabolisms across the YNP geothermal complex in an effort to better understand the foundation for the observed habitat range of phototrophs in YNP. Generalized Additive Models (GAMs) were built using this binary dataset of independent observations in order to quantify and rank the influence of temperature, pH, and total sulphide on the habitat range of phototrophs. Using this method, it was found that temperature, dissolved sulphide concentration, and pH were the main predictors of the spread of phototrophs in YNP springs. We tested these hypotheses using one-hour-long microcosm investigations in a few particular geothermal springs.