Supplementary Material

Table of contents

Figure S1 – The velocity of climate change depends on the spatial resolution of climate data

Figure S2 – Rate of dispersal relative to the velocity of climate change often depends on whether average or extreme values are used

Table S1 – Full set of linear models fit to range shift observations including contractions

A graph showing the scale of climate velocity

Description automatically generated with medium confidence

Figure S1. The velocity of climate change depends on the spatial resolution of climate data.

A screenshot of a computer

Description automatically generated

Figure S2. Whether species’ potential dispersal rates are slower than the velocity of climate change sometimes depends on whether mean or p90 climate velocity or a maximum or median potential dispersal rate is used.







Table S1. Full set of linear models testing whether species’ observed range expansion rates (including extreme contractions, i.e., extreme negative expansions) are best explained by species’ potential dispersal rates, the velocity of climate change, both (additively and interactively), or the minimum of the two (i.e., the minimum rate). The velocity of climate change models fit the response variable (observed range expansion rate; continuous, km/y) as a function of the velocity of climate change across the occupied study area (either mean or 90th percentile, p90), while the potential dispersal rate models fit the response variable as a function of the species’ potential dispersal rate (either maximum or median) alone or with an additive or interactive effect of the velocity of climate change. The minimum rate models fit the response as a function of the minimum of the species’ potential dispersal rate and the velocity of climate change.

| Model | Velocity of  climate change | Dispersal distance | Parameter | Estimate | Std. Error | t-value | p-value | R2 | n | K | LL | AICc | ΔAICc |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Velocity of climate change | Mean | - | Intercept | 0.2 | 0.26 | 0.79 | 0.43 | 0.02 | 447 | 3 | -1296.4 | 2598.86 | 0 |
| Velocity of climate change | 0.23 | 0.09 | 2.63 | 0.01 |  |  |  |  |  |  |
| Minimum rate | Mean | Max | Intercept | 0.24 | 0.25 | 0.94 | 0.35 | 0.02 | 447 | 3 | -1296.46 | 2598.97 | 0.11 |
| Minimum rate | 0.23 | 0.09 | 2.61 | 0.01 |  |  |  |  |  |  |
| Minimum rate | p90 | Max | Intercept | 0.2 | 0.26 | 0.75 | 0.46 | 0.01 | 447 | 3 | -1296.49 | 2599.04 | 0.18 |
| Minimum rate | 0.15 | 0.06 | 2.6 | 0.01 |  |  |  |  |  |  |
| Velocity of climate change | p90 | - | Intercept | 0.11 | 0.29 | 0.38 | 0.7 | 0.01 | 447 | 3 | -1296.72 | 2599.5 | 0.64 |
| Velocity of climate change | 0.15 | 0.06 | 2.51 | 0.01 |  |  |  |  |  |  |
| Minimum rate | Mean | Median | Intercept | 0.27 | 0.25 | 1.08 | 0.28 | 0.01 | 447 | 3 | -1297.01 | 2600.07 | 1.22 |
|  |  |  | Minimum rate | 0.23 | 0.1 | 2.39 | 0.02 |  |  |  |  |  |  |
| Potential dispersal rate: additive | Mean | Median | Intercept | 0.23 | 0.26 | 0.89 | 0.37 | 0.02 | 447 | 4 | -1296.1 | 2600.28 | 1.43 |
| Potential dispersal rate | 0 | 0 | -0.78 | 0.44 |  |  |  |  |  |  |
| Velocity of climate change | 0.25 | 0.09 | 2.73 | 0.01 |  |  |  |  |  |  |
| Potential dispersal rate: additive | Mean | Max | Intercept | 0.2 | 0.26 | 0.78 | 0.43 | 0.02 | 447 | 4 | -1296.4 | 2600.89 | 2.03 |
| Potential dispersal rate | 0 | 0 | 0.04 | 0.97 |  |  |  |  |  |  |
| Velocity of climate change | 0.23 | 0.1 | 2.35 | 0.02 |  |  |  |  |  |  |
| Potential dispersal rate: additive | p90 | Median | Intercept | 0.13 | 0.29 | 0.46 | 0.65 | 0.01 | 447 | 4 | -1296.51 | 2601.11 | 2.26 |  |
| Potential dispersal rate | 0 | 0 | -0.65 | 0.52 |  |  |  |  |  |  |  |
| Velocity of climate change | 0.16 | 0.06 | 2.57 | 0.01 |  |  |  |  |  |  |  |
| Minimum rate | p90 | Median | Intercept | 0.28 | 0.26 | 1.08 | 0.28 | 0.01 | 447 | 3 | -1297.63 | 2601.31 | 2.46 |  |
| Minimum rate | 0.15 | 0.07 | 2.11 | 0.04 |  |  |  |  |  |  |  |
| Potential dispersal rate: additive | p90 | Max | Intercept | 0.11 | 0.29 | 0.37 | 0.72 | 0.01 | 447 | 4 | -1296.68 | 2601.46 | 2.6 |  |
|  |  | Potential dispersal rate | 0 | 0 | 0.28 | 0.78 |  |  |  |  |  |  |  |
|  |  | Velocity of climate change | 0.14 | 0.06 | 2.23 | 0.03 |  |  |  |  |  |  |  |
| Potential dispersal rate: interactive | Mean | Median | Intercept | 0.21 | 0.27 | 0.78 | 0.44 | 0.02 | 447 | 5 | -1295.82 | 2601.78 | 2.93 |  |
|  |  | Potential dispersal rate | 0 | 0.01 | 0.29 | 0.77 |  |  |  |  |  |  |  |
|  |  | Velocity of climate change | 0.27 | 0.1 | 2.82 | 0.01 |  |  |  |  |  |  |  |
|  |  | Potential dispersal rate: velocity of climate change | 0 | 0 | -0.73 | 0.46 |  |  |  |  |  |  |  |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Potential dispersal rate: interactive | p90 | Median | Intercept | 0.11 | 0.3 | 0.37 | 0.71 | 0.02 | 447 | 5 | -1296.37 | 2602.88 | 4.02 |  |
|  |  | Potential dispersal rate | 0 | 0.01 | 0.28 | 0.78 |  |  |  |  |  |  |  |
|  |  | Velocity of climate change | 0.17 | 0.06 | 2.6 | 0.01 |  |  |  |  |  |  |  |
|  |  | Potential dispersal rate: velocity of climate change | 0 | 0 | -0.53 | 0.6 |  |  |  |  |  |  |  |
| Potential dispersal rate: interactive | Mean | Max | Intercept | 0.19 | 0.27 | 0.69 | 0.49 | 0.02 | 447 | 5 | -1296.38 | 2602.89 | 4.04 |  |
|  |  | Potential dispersal rate | 0 | 0 | 0.2 | 0.84 |  |  |  |  |  |  |  |
|  |  | Velocity of climate change | 0.24 | 0.11 | 2.27 | 0.02 |  |  |  |  |  |  |  |
|  |  | Potential dispersal rate: velocity of climate change | 0 | 0 | -0.21 | 0.83 |  |  |  |  |  |  |  |
| Potential dispersal rate: interactive | p90 | Max | Intercept | 0.11 | 0.3 | 0.37 | 0.71 | 0.01 | 447 | 5 | -1296.68 | 2603.5 | 4.64 |  |
|  |  | Potential dispersal rate | 0 | 0 | 0.07 | 0.94 |  |  |  |  |  |  |  |
|  |  | Velocity of climate change | 0.14 | 0.07 | 2.07 | 0.04 |  |  |  |  |  |  |  |
|  |  | Potential dispersal rate: velocity of climate change | 0 | 0 | 0.06 | 0.95 |  |  |  |  |  |  |  |
| Potential dispersal rate | - | Max | Intercept | 0.51 | 0.23 | 2.24 | 0.03 | 0 | 447 | 3 | -1299.16 | 2604.38 | 5.52 |  |
|  |  | Potential dispersal rate | 0 | 0 | 1.18 | 0.24 |  |  |  |  |  |  |  |
| Potential dispersal rate | - | Median | Intercept | 0.63 | 0.22 | 2.86 | 0 | 0 | 447 | 3 | -1299.82 | 2605.69 | 6.83 |  |
|  |  | Potential dispersal rate | 0 | 0 | -0.28 | 0.78 |  |  |  |  |  |  |  |