**Introduction**

Bumble bees are vital pollinators in natural and managed ecosystems, but many local populations are in decline (Cameron et al. 2011). These local declines are likely due in part to changing climate given that recently documented range shifts and contractions of bumblebee species in North America and Europe are clearly climate driven (Kerr et al. 2015). Bumble bees and other organisms may escape warming temperatures by moving poleward or upslope to cooler climates. However, flying organisms that move upslope encounter reduced air density which may increase the energetic costs of flight and compromise flight performance (Feinsinger et al. 1979; Dillon, Frazier & Dudley 2006). To determine whether this aerodynamic challenge may limit upslope range shifts in flying organisms like bumble bees, we asked whether contemporary high-altitude residents have compensatory changes in flight morphology to cope with decreased air density. Specifically, low air density should select for larger wings relative to body size (lower wing loading), reducing the energetic costs of flight at high altitudes. Finding reduced wing loading with elevation would suggest that upslope range shifts that would allow bumblebees to track permissive temperatures may be precluded by the aerodynamic challenges of reduced air density.

**Methods**

Figure 1. We collected bumble bees from 115 sites across western North America varying in elevation from sea level to 3000 m. We collected across the growing season in 2013-2015 to account for seasonal variation in activity and morphology. *B. vosnesenskii* (N=1166, black points) is broadly distributed whereas *B. bifarius* (N=658) is predominately found at mid to high elevations. Wet mass was measured immediately after capture to the nearest mg.

Figure 2. After transport to the lab, one or both sets of wings from each bee were mounted on microscope slides with tape. Scanned wing images (left) were digitally traced (middle, program Gimp) and then thresholded (right) to determine total wing surface area (Image J).

**Results**

Figure 3. Variation in mean field mass (indicated by point size, see legend at top right) collected at sites spread across latitude and altitude for *B. vosnesenskii* (black points) and *B. bifarius* (orange points). Field mass did not change with latitude or altitude (ANOVA, both P>0.104) for *B. vosnesenskii*. *B. bifarius* tended to be larger at more northern latitudes (loosely coinciding with lower elevations; ANOVA, P<0.001).

Figure 4. Hypometric scaling of wing area with body size drives increased wing loading in larger bees, potentially increasing energetic costs of flight. *B. bifarius* had smaller wings relative to body mass than did *B. vosnesenskii*, leading to relatively higher wing loading. [Wing loading data not shown]

**Discussion**

- *B. vosnesenskii* showed no significant variation in field mass or wing loading across latitude or altitude. *B. bifarius* tended to be larger at higher latitudes and to have reduced wing loading with elevation at elevations above ~2000 m.
- Below 2000 m, upslope range shifts of bumble bees may not be constrained by aerodynamic considerations. However, range shifts to elevations above 2000 m may be require compensatory changes in flight morphology to overcome energetic and aerodynamic costs of flight in reduced air densities.

**References**


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