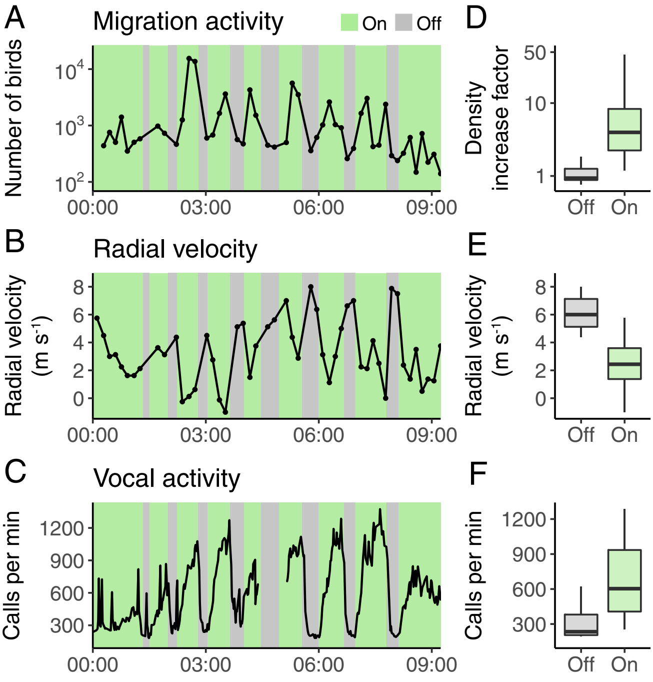

Fig. 2. Time series of radar and acoustic measures of Tribute in Light impact on migratory birds. Observations (in Coordinated Universal Time) from September 11–12, 2015 of (*A*) migration activity within 500 m of the installation, (*B*) radial velocity within 500 m of the installation, and (*C*) vocal activity during periods of TiL illumination. *D*–*F* show corresponding data with and without illumination. Density increase factor (*D*) is defined as the peak bird density near the installation divided by the mean density 2–20 km away.

these effects were also significant in the high altitude 1.5° radar data (total numbers: factor = 1.9 times, t = 3.49, P = 0.0006; standardized peak density: factor = 4 times, t = 4.00, P < 0.0001). Radial velocities were significantly lower during illuminated periods (main effect = -1.7 ms^{-1}, t = -2.10, P = 0.037), especially during 2012 (effect with interaction = -5.4 m/s, t = -2.38, P = 0.02) and 2015 (effect with interaction = -4.3 m/s, t = -2.52, P = 0.01). Flight call rates recorded beneath the installation were significantly higher during illuminated periods (main effect = 1.4 times, t = 4.53, P < 0.0001), especially in 2015 (factor with interaction = 2.9 times, t = 6.88, P < 0.0001); the effect was reduced in 2013 (factor with interaction = 1.1 times, t = -2.30, P = 0.02). Because our model of vocal activity included bird density as a predictor to account for variation in calling explained by the sheer quantity of birds, the significant increases in calling with illumination can be attributed primarily to behavioral differences.

Simulation results showed that birds were highly likely to become disoriented as they approached the installation (*SI Appendix*, Fig. S8). The model matching radar observations most closely (model 1; Fig. 4 and *SI Appendix*, Tables S1 and S2) had disorientation probability a = 0.95, indicating a very high likelihood of disorientation near ALAN, and the characteristic disorientation distance (σ) was 1,500 m. The concentrations of birds observed at the installation could only be explained by including directed flight toward ALAN for disoriented birds (concentration parameter $\kappa > 0$; best model $\kappa = 0.1$). In contrast, simulated birds diffused easily away from ALAN when assuming a nondirectional random walk ($\kappa = 0$; model 3 in *SI Appendix*, Table S1). These results support our visual observations of birds circling around the installation and are indicative of light attraction.

The stabilization time to a steady-state increased with disorientation probability (a) and flight directionality toward ALAN (κ) (Fig. 4, Movies S4–S8, and *SI Appendix*, Table S1). The stabilization time provides information on the residence time of birds in the beam, as a steady state is only reached over time periods longer than the average residence time. Our model 1, which is conservative in this regard, predicts a stabilization time of 34 min. We note that this is the result of average behavior for all birds contributing to the density pattern, and individual residence times may be considerably longer or shorter. Our simulation provides a theoretical framework for explaining our visual and remotely sensed observations, underscoring that the light installation attracted and entrained passage migrants.

Finally, direct visual observations showed that birds frequently circled the installation during periods of illumination and decreased speed on approach to the installation (*SI Appendix*). Such observations also highlighted a particular hazard that nocturnally migrating birds face in urbanized areas with ALAN: collisions with structures. Observers noted in 2015 and 2016 that many birds collided with the glass windows of a building under construction just north of the lights (50 West Street; Fig. 1*A*). The full extent of mortality was not clear, primarily because of challenges surveying nearby sites, scaffolding preventing birds from falling to ground level, and removal of carcasses by scavengers and building staff. We therefore do not have sufficient data to analyze mortality with respect to illumination and migration intensity. However, existing data are archived in the New York City Audubon D-Bird database (https://d-bird.org/).

Discussion

This study quantifies ALAN-induced changes in multiple behaviors of nocturnally migrating birds. Our data show that the light installation strongly concentrates and disorients migrants flying over a heavily urbanized area, influencing ≈1.1 million birds during seven nights over 7 y.

Existing published accounts report attraction to lights almost exclusively under poor-visibility conditions (45, 53), but our results show alterations to migrants' behaviors in clear and mostly clear

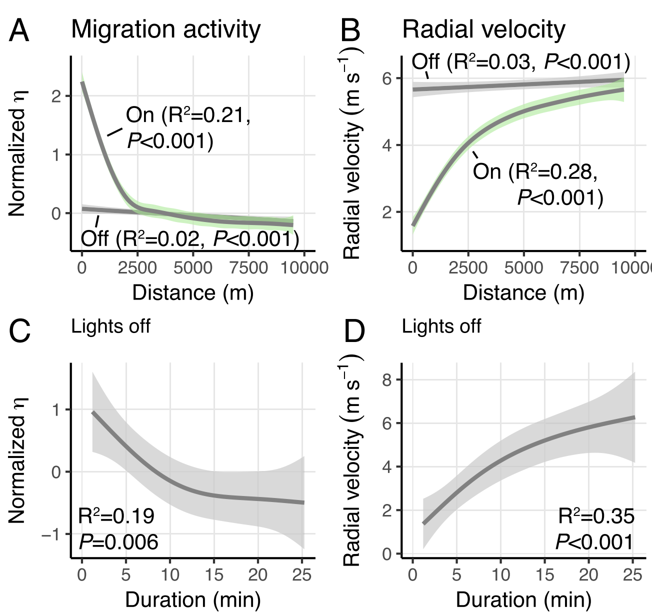

Fig. 3. Spatial and temporal influence of Tribute in Light on migratory birds. Migration activity (*Left* column) and radial velocity (*Right* column) at the installation pooled across years by distance from the study site (*A* and *B*) and activity as a function of time since TiL shutdown (*C* and *D*). To account for year-to-year variation, migration activity was normalized across years using a z-score standardization (values minus the nightly mean, divided by the nightly SD). Illumination represented by green and periods without illumination by gray. *C* and *D* include only measures ≤500 m from the installation. Data fit with generalized additive models (*A* and *B*: bs = "cs," m = 2, k = 10; *C* and *D*: bs = "ds," m = 2, k = 5) and weighted by migration activity for radial velocity models. Shading represents 95% confidence intervals.