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Assessing biological and environmental effects of a total solar eclipse with passive multimodal technologies

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ABSTRACT

On 21 August 2017, a total solar eclipse crossed the continental United States, providing a unique natural experiment to observe how wildlife and plants respond to rapid and drastic changes in photic conditions using a multi-modal suite of tools. We installed passive time-lapse and infrared cameras, sound recorders, and data loggers in the Central Platte River Valley of Nebraska to study this phenomenon. The eclipse lasted about three hours, and complete obscuration of the sun (totality) lasted for about 2 min and 30 sec. Light values, measured with time-lapse camera systems, decreased 67% on average during totality relative to the daily mean light value. Ambient temperatures decreased by 6.7 °C on average (12% of the daily mean) approximately 11–16 min after totality; concurrently, humidity increased by an average of 12% of the daily mean. We found evidence for altered acoustic activity in response to the eclipse, including site and species-specific changes in the call activities of late season breeding birds and insects in the orders orthoptera and hemiptera. In addition, acoustic indices were differentially correlated with changes in photic and thermal conditions. However, we did not observe changes in flowering plants nor detect bat activity at known night roost and foraging areas. Historically, observations during rare occurrences, such as a total solar eclipse, were anecdotal or limited in scope, and thus, how they changed the light, sound, and meteorological conditions on the landscape were difficult to validate and measure. In comparison, anthropogenic disturbances, including impacts from light pollution and climate change, often take place slowly over long periods, and therefore, can be complex and challenging to assess. Documentation of this stochastic occurrence, with an immediate change in environmental conditions, highlights the utility of passive multimedia technologies to increase our capacity to monitor ecosystem dynamics and chronicle the variations of abiotic properties of a landscape and concomitant responses of organisms with varying sensory abilities.

1. Introduction

Sunlight is one of the foremost abiotic mechanisms governing the natural world. As the primary source of energy on Earth, solar radiation dictates atmospheric conditions and structures the biological world (Ramanathan et al., 2001; Wild et al., 2005). Light-dark cycles act as a reliable environmental cue to regulate circadian and circannual rhythms in plants and animals, facilitating synchronization of physiological and biological responses with temporal niches (Shuboni and Yan, 2010), including dormancy/hibernation, migration, and reproduction (Helm et al., 2013). However, human-caused disturbances, such as light pollution and climate change, have altered environmental conditions and destabilized biological rhythms (Bradshaw and Holzapfel, 2010; Gaston et al., 2013). As these disturbances often occur gradually over an extended period (decades), observing and evaluating biotic and abiotic responses is often challenging due to the temporal

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limitations of datasets, the complexity of parsing apart interacting factors over time, and the inconspicuousness of gradual changes.

On 21 August 2017, a total solar eclipse provided a rare natural experiment to investigate the response of organisms and atmospheric conditions to an immediate and concentrated drastic reduction in solar intensity. As the moon aligned between the earth and sun, a 95–115-km wide shadow crossed from the northwestern to southeastern United States, traversing the Great Plains and Central Platte River Valley in south-central Nebraska, where obscuration of the sun reached 100%. Although this periodic phenomenon is relatively frequent, about two to four times a year, the limited spatial scope reduces the observational opportunity to approximately once every hundred years for any given location (NASA, 2017). The last total solar eclipse in the continental United States occurred 26 February 1979, and was visible from only five northwestern states (NASA, 2017). Due to this infrequency, there is sparse information available about the response of flora and fauna concurrent with atmospheric changes during eclipses.

An event rooted in the mythical and spiritual fascination of mankind, there exists an abundance of total solar eclipse guides (Littmann et al. 2008) and narratives, including folklore telling of an eternal bat gnawing at the moon (Deutsch, 2017), humbling personal revelations (Tamarkin, 2017), and even news stories reporting on the abundance of solar eclipse-related media coverage throughout history (Kutner, 2017). However, documented observations of plant and animal responses to an eclipse are limited and often rely on anecdotal accounts rather than systematic observations. A comprehensive report of plant and wildlife sightings reported to newspapers and interspersed with accounts from natural history experts during eclipses from 1544 to 1932 notes birds stopped singing, crickets began chirping, and bees returned to their hive during totality (Wheeler et al., 1935). More recent studies examining the effect of an eclipse on biota have found varied results and often rely on manual observations that can be species-specific or limited in scope. During an eclipse, documented variations in animal behavior include birds ceasing to call (Hughes et al., 2014), diurnal fish seeking shelter (Jennings et al., 1999), spiders destroying their webs (Uetz et al., 1994), and captive animals, such as chimpanzees, hamadryas baboons, and antelope ground squirrels altering their activity (Kavanau and Rischer, 1973; Branch and Gust, 1986; Gil-Burmann and Beltrami, 2003). Bats in Mexico were recorded flying down a ravine during a total solar eclipse, however at the same time and location, monitoring of cave-dwelling bats found no changes in behavior (Sanchez et al., 1999). Albeit, some animals have not responded to changing light conditions during these rare occurrences; dairy cows demonstrated no change in rumination during a total eclipse (Rutter et al., 2002), and European ground squirrels (*Spermophilus citellus*) demonstrated no change in burrowing behavior during a partial eclipse (Spoelstra et al., 2000). Additionally, a limited number of studies have observed various responses of plants to total solar eclipses, including the opening and closing of leaf stomata in grey birch (*Betula populifolia*) (Deen and Bruner, 1933), opening and closing of Helianthemum (*Helianthemum vulgare*) flowers (Kullenberg, 1955), and a change in the photosynthetic activity of crops and marine plankton (Economou et al., 2006). Although informative, many studies assessing biological effects of an eclipse have had a mono-specific focus. Increasingly, emerging technologies are being used to understand multimodal responses to disturbance, assess ecological condition, inform conservation actions, and communicate through novel techniques (Blumstein et al., 2011; Sueur and Farina, 2015; Brinley Buckley et al., 2017; Raynor et al., 2017). Integration of these technologies into a suite of multi-modal tools can support investigations of ecological responses at various spatio-temporal scales, including community-level responses to a unique event (Allan et al., 2018).

The objective of our study was to capture and quantify changes in atmospheric conditions and behavioral responses by a variety of biota to a total solar eclipse that occurred in North America on 21 August 2017. To measure these effects, we installed passive monitoring equipment, including time-lapse camera systems and audio recording devices, in diverse habitats associated with the Platte River in south-central Nebraska, USA. We sought to i) describe how atmospheric conditions and biological activity change before, during, and after the eclipse and ii) demonstrate how different methods, notably photography and soundscape recordings utilizing image processing and acoustic indices, capture atmospheric and biotic responses to abrupt changes in sunlight. Specifically, we first hypothesized that flowering species of vascular plants (Dicotyledoneae) known to bloom periodically under particular light conditions (morning, night, etc.; Raguso et al., 2003; Atamian et al., 2016) or track the movement of the sun, would alter their daily rhythm during the eclipse. Secondly, we monitored two known bat foraging locations with ultrasonic recorders, as well as a known roosting location for insectivorous bats and an active wildlife corridor with two motion-activated cameras, hypothesizing that the eclipse would initiate activity for bats and additional crepuscular wildlife. Lastly, we hypothesized that the eclipse would influence vocalization patterns of birds and calling insects, like crickets, cicadas, and grasshoppers, known to respond to various levels of light and atmospheric conditions (Heller and Von Helversen, 1993; Greenfield, 1997; La, 2012; Bruni et al., 2014).

2. Materials and methods

2.1. Study area

The path of the solar eclipse spanned the northwestern to the southeastern United States on 21 August 2017 (Fig. 1a). Our study was conducted in south-central Nebraska, USA, near the Platte River, a biologically unique and important landscape (Fig. 1b; Schneider et al., 2005). Here the eclipse lasted for 2 hr and 52 min, from 11:34 h to 14:26 h (Central Daylight Time; CDT). The sun was 100% obscured (totality) for approximately 2 min and 34 sec between 12:58 h and 13:01 h CDT at an altitude of 60.0° at 161.8° SSE (NASA, 2017). We deployed monitoring equipment across three locations managed for habitat conservation: Mormon Island of the Crane Trust (2,025 ha; 40.798306°N, −98.416298°W; 581 m elev.), Shoemaker Island of the Crane Trust (40.7902345° N, −98.4675122° W; 595 m elev.), and Audubon's Rowe Sanctuary (980 ha; 40.669323° N, -98.887926° W, 633 m elev.) (Fig. 1c). These locations consisted of relict and restored subirrigated prairies and meadows, as well as riparian woodlands adjacent to the Platte River (Currier, 1989, 1982; Nagel and Kolstad, 1987). Across these locations, we studied specific sites and habitats that included a wet meadow (Mormon Island), riparian woodland (Rowe Sanctuary), and a trout pond, beaver lodge, utility garage with a bat roost, and a cottonwood savanna (all on Shoemaker Island).

2.2. Equipment

Time-lapse imagery, sound recordings, and data loggers collected information from 20 August 2017 to 22 August 2017, however the primarily focus to assess changes related to the eclipse was from 10:30 to 15:30 CDT, one hour before the onset of the partial eclipse phase to one hour after the completion of the eclipse, on 21 August 2017 (see Supplementary Material: Passive Monitoring Equipment for further details).

Images were collected from two cameras, one on Mormon Island and one at Rowe Sanctuary, which are part of a network of time-lapse camera systems extending through the Platte River watershed of the Great Plains as part of the Platte Basin Timelapse (PBT) project (www.plattebasintimelapse.org). Each time-lapse camera system included a Nikon D300 (Exposure compensation: -0.3, ISO: 400; aperture-priority: Rowe Sanctuary- f/9, Mormon Island f/8) within water resistant housing and powered by a solar panel. An intervalometer engineered by TRLcam remotely controlled the capture interval via wireless and satellite connections (TRLcam.com, Lincoln, Nebraska). During the day of