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Wingstrokes: Linking migration citizen science data for Blue-headed & Red-eyed Vireos to spring climate in Vermont as depicted visually in art

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Research & Creative Arts Thesis

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Abstracts

Part 1

Bird migration is just one example of how accelerating environmental variation caused by climate change has imposed pressure on organisms to adapt more quickly than the background pace of evolution. The timing and spatial orientation of bird migration is crucial for successful breeding and the long term survival of species. If the window of optimal breeding conditions is shifting with changing climate, it is crucial to understand the flexibility that species have to alter their migration patterns, if at all. I used citizen science data from eBird.org to observe mean arrival day of both Blue-headed Vireo (*Vireo solitarius*) and Red-eyed Vireo (*Vireo olivaceous*) in Vermont from 2008 through 2015. The correlation between the monthly temperature and mean arrival date for these species was assessed through multivariate regression modeling. The most significant determinants of arrival day for these two species were elevation and latitude, which can be used as proxies for climate (n = 843, $p < 0.001$, r2 = 0.45). The methods and insight into the strengths and limitations of citizen science can be used to inform further research and wildlife management.

Part 2

Scientific discoveries are often limited to circulate among those in the discipline and never reach the general public. It is important however to bring the public into the conversation, especially for issues regarding conservation. Art is one medium that is growing as a means of communicating science to a broader audience. By using emotion, visual representation, and metaphors, scientists may be able to present their findings in a more approachable and inclusive way. The collaboration of art and science is a movement that is especially growing in ecological and environmental fields because it can tap into people's preexisting personal value for the environment and nature. The findings from this study, the biological story of the two Vireo species, and their interactions were translated into paintings that were put on display in a public exhibit. Voluntary surveys aimed to quantify viewers' opinions about using art and science collaboratively as well as the effectiveness of the exhibit at communicating scientific content. There was a diverse range of participants, and most expressed opinions that strongly supported the goals of the exhibit, the use of art and science collaboratively, and to a lesser extent the exhibit's effectiveness at communicating scientific content.

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PART 1

Overview

Temperate latitudes around the globe are experiencing more unpredictable vernal transitions. Compared to historic trends, springs have been warming earlier in these regions. This has led to increased selection pressures on organisms to adapt to these changes. Adaptations that usually take generations to evolve now need to adjust more rapidly. Although naturally occurring climate change is a consistent driver of adaptation, human-exacerbated climate change is causing greater rates of extinction than background levels (IPCC 2014).

One taxon that has shown signs of rapid adaptation is birds. Birds serve many important roles, and their presence and abundance in certain ecosystems may change over time and space as a result of climate change. This is especially true for migratory species, and monitoring changes in avian migration patterns is vital for effective ecosystem management. With increasingly rapid changes in climate, species may need to adjust their migration timing to continue to breed successfully. Breeding success, which greatly determines fitness, heavily relies on resource availability which in turn is shifting with changing climate. Therefore, it is vital to adjust breeding timing and migration timing accordingly to remain synchronous with climate.

This thesis focused on the Blue-headed Vireo (*Vireo solitarius*) and the Red-eyed Vireo (*V. olivaceus*) and their spring arrival in Vermont. In Part 1, the relationship between climate change and the mechanisms behind migration patterns and the potential for employing citizen science in ecological research were investigated. This was accomplished by conducting spatial and statistical analyses using citizen science and spatial climate data.

II. Literature Review

Migration

Migration is one of many behavioral tactics that species have evolved to maximize their chance of survival and successful reproduction. As a behavior that is reliant on spatial and temporal sensitivity to varying degrees, there is a complex system of influential factors and consequences at play. It is vital to understand the driving mechanisms of migration to best predict its future changes and the possible reverberating effects on the biosphere.

Migratory birds travel between continents and hemispheres, making them important species in a vast range of ecosystems and biogeographical regions. Because they are so diverse in their niches and trophic levels, birds play many important roles in their respective ecosystems including seed dispersal, predation, scavenging, pollination, and ecosystem engineering (Courter et al. 2013). Tracking changes in their migratory patterns is just as important as monitoring population size because if a species no longer passes through or returns to a certain area, the consequences will be comparable to local extirpation. It is therefore crucial to the longevity and integrity of ecosystems across the globe to monitor, study, and predict changes in avian migratory patterns.

Why migrate?

To successfully reproduce, a species needs to find the habitat with sufficient resources and also to out-compete others for the use of those resources. Because of the Earth's seasonality, resource variability in nearly every ecosystem is directed by seasonal variations in sunlight, temperature, and precipitation. An ideal habitat would have continuous resource availability and therefore allow continuous breeding through the year because of constant ideal conditions (Parker & Courtney 1983). In a habitat without continuous resource availability however, organisms need to adapt a strategy for coping with these fluctuations (Parker& Courtney 1983; Alerstam & Hedenstrom 1998). This could involve behaviors such as hibernation, physiological changes, food storage, or migration.

Reproduction is one of the most intensive requirements for resources. A breeding adult needs to acquire resources for both itself and its offspring during the entire breeding cycle from mate choice through rearing (Martin 1987). A species tends to breed at a time in its annual cycle that provides the best conditions for success and will ensure the survival of both parent and offspring (Verhulst & Nilsson 2008). Many species migrate between a breeding ground with sufficient seasonal resources and a wintering ground which is provides resources when seasonal conditions in the breeding ground become less favorable (Alerstam & Hedenstrom 1998). It is essential to utilize the window of time during the year that is best for breeding because an individual's fitness is primarily determined by breeding success (Visser et al. 2004). As this window shifts, those individuals with the ability to respond to favorable conditions will out-compete those that do not (Fuller 2012). Annual shifts are in most cases relatively minor, but migrating even several days before or after the rest of the population can determine if that individual mates and gets the best territory or resources.

Consequently, it is theoretically advantageous to arrive at breeding grounds early in order to quickly find the best mate (Kokko 1999). However, as with any evolutionary behavior, there are tradeoffs. Migrating too early can mean encountering less favorable conditions while flying, arriving before the resources are available, and/or not being physically prepared to make the journey (Kokko 1999). This can threaten an individual's survival as well as its ability to successfully reproduce. Thus, the timing of migration between breeding and wintering habitat is crucial to the survival of the entire species, not just the individual.

Cues

Because of the importance of migratory timing, there are many cues that species have evolved that serve as correlates for the optimal departure time. These cues can be categorized into two classes: endogenous and exogenous. Endogenous, literally meaning 'coming from within', describes cues that are physiological or intrinsic to the bird, such as fat accumulation and molt patterns. These cues are hypothesized to be a possible physical limitation on when the bird is able to migrate (Pulido, F., & Coppack, 2004).

Exogenous cues stem from the bird's external environment. The two most common exogenous cues are photoperiod and temperature (Hurlbert & Zhongfei 2012). The daily ratio of daylight and darkness is used by many species to determine when to migration. Photoperiod can be considered a reliable cue in that it does not vary year to year, being dependent on Earth's tilted axis and therefore independent from climate (Coppack & Both 2002). The tradeoff with using temperature for a cue is that while it can vary greatly year to year, it is also a determinant of many other biological events which in turn control resource availability and habitat suitability. In this way, using temperature as a cue allows birds to stay synchronous with resource availability in their breeding habitat from year to year. A species must evolve to utilize the best combination of cues to time their migration and maximize survival and breeding success.

Synchrony & asynchrony

Temperature synchrony

As alluded to above, the correlation in timing of biological events is referred to as synchrony. The arrival of insectivorous birds on the breeding grounds is in part determined by the of timing leaf out (Parker & Courtney 1983; Kullberg et al. 2015; Marra et al. 2005; Courter et al. 2013). Vernal warming plays a large part in inducing new plant growth, usually represented by onset of initial bud burst. This in turn dictates the timing of the boom in herbivorous insects such as caterpillars. As a main food source for many birds (and in particular their young), synchronizing breeding with these phenological events is critical (Kullberg et al. 2015). This dependency connects spring temperature to the optimal breeding window and thus migration timing. Temperature has shown a strong correlation with avian arrival date in Europe and North America as far back as the 1800s, showing that with gradual warming comes earlier arrival (Kullberg et al. 2015).

Existing evidence of asynchrony

There have been numerous studies tracking how different organisms are responding to changing climate. As mentioned before, earlier warm temperatures have been shown to significantly advance the date of bud-burst and leaf-out in many areas (Primack et al. 2015; Visser & Holleman 2001). As these events determine annual insect population booms, many bird species need to trace these patterns not only at their destination but also at stopover locations along their route (Marra et al. 2005). Conversely, warming temperatures may also delay this chain of events. Many plant species require a certain amount of time at cold temperatures before warming in spring to induce growth. Milder winters can lead to a delay in bud-burst and leaf-out (Courter et al. 2013). Although manifesting in a variety of different ways, changes in temperature trends are causing rapid variations in ecosystems across the globe.

There has also been research on a variety of bird species to identify the relathionship between temperature and migration timing (Both, 2010; Both et al. 2006; Courter et al. 2013; Van Buskirk 2012; Visser & Both 2005). For example the European Pied Flycatcher (*Ficedula hypoleuca)* has been the focus of many studies in Europe. Its arrival date to Scandinavia has advanced 10 days from 1980 to 2002 as it migrates from North Africa (Both, 2010). North American raptors have extended their stay in breeding grounds nearly 30 days over the past 30 years by arriving earlier and departing later (Van Buskirk, 2012). This type of breeding season extension has been observed in other types of birds as well (Lehikoinen et al. 2004).

Long- versus short- distance migrants

In general there are two categories of migratory species: short-distance and long-distance migrants. Long-distance migrants travel between continents to utilize optimal breeding and wintering habitat while in general short-distance migrants migrate within one continent. Long- and short- distance migrants have been shown to employ different cues in determining departure. There is strong evidence that long-distance migrants tend to utilize endogenous cues and the exogenous cue of photoperiod while short-distance migrants tend to more heavily rely on exogenous climatic cues such as temperature to determine departure (Both & Visser 2001). This may explain why short-distant migrants have been observed migrating earlier in response to warming temperatures and are therefore arriving in their breeding grounds earlier in some regions (Swanson & Palmer 2009; Kullberg 2015; Lehikoinen, 2014). Long-distance migrants are not responding as synchronously to temperature change because many of them rely on cues other than climate. Since climate change does not affect the earth uniformly, climatic variation is likely to be different between breeding and wintering grounds (Cox 2010). This reduces their ability to remain synchronous with the phenology on their breeding grounds.

Study species: Red-eyed & Blue-headed Vireos

This investigation compared two migratory songbird species that breed in Vermont: Red-eyed Vireo (*Vireo olivaceus*) and Blue-headed Vireo (*Vireo solitarius;* Figure 1 A & B). They were chosen as the focus species for several reasons. In addition to being closely related phylogenetically, these songbirds are similar in many other characteristics. Their breeding grounds extend across the northern and eastern United States. Both prefer the interiors of middle aged to mature forests in elevations up to 600 meters. They typically prey on medium to large insects both for themselves and their offspring. Their nests are cup shaped and suspended in the fork of a small branch in the mid or under story. Regarding their phenology, *V. olivaceus* migrates from mid-April to early June and breeds early May to late August. *V. solitarius* migrates early April to early June and breeds mid-May to early August. Because there is such a degree of overlap between these two species, many potentially confounding factors are controlled, allowing for a better comparison of the effect of migration distances. *V. olivaceus* undergoes a long-distance migration, wintering in northern South America and Brazil, while *V. solitarius* migrates a short distance, wintering along the Gulf Coast of the United States (Cimprich 2000; Morton et al. 2014; Blue-headed Vireo 2016; Red-eyed Vireo 2016; Figure 2 A & B). In addition, these species were chosen because of their relatively even presence across the state of Vermont and ubiquity during breeding season.

Previous research has been conducted on these two species' breeding and migration behaviors. Most research on the migration of *V. olivaceus* has investigated their stopover sites (Woodworth et al. 2014; Cohen et al. 2014; Callo et al. 2013), while research on *V. solitarius* has focused on their breeding ecology (Chiver & Stutchbury 2007; Van Roo 2003). There have been no in depth analyses or direct comparisons of these two species' migration strategies. This study hypothesized that there is a significant correlation between spring temperature and arrival day for these two species.

III. Methods

Data collection & sources

The arrival of *V. solitarius* and *V. olivaceus* was modeled using data provided by the Cornell Lab of Ornithology's eBird citizen science database. The site name, year, latitude, longitude, and date of observation in Julian Day (JND) of all hotspot locations where that species was reported in the months of April and May for 2008 through 2015 were compiled into one dataset. A hotspot is defined by the Cornell Lab of Ornithology as a public location that is regularly visited and approved by a database administrator. Only hotspots were used in this analysis because they are more frequently visited, yielding a more consistent sample size, and allowing for consistent spatial data across years.

All climatic data were acquired from the University of Oregon's PRISM Climate Group online archive (PRISM 2008-2015). Nation-wide ASCII maps were downloaded for the monthly minimum, mean, and maximum temperature in degrees Celsius for April and May for 2008 through 2015. These files were converted into raster layers in ArcMap software (v 10, ESRI, Redlands, California, USA) and clipped to the extent of Vermont for more efficient processing.

The digital elevation model and the shapefile for the six biophysical regions for the state were downloaded from the Vermont Center for Geographic Information (Vermont Center for Geographic Information, n.d.).

Defining mean arrival date (MAD)

Although there are a variety of methods used to define mean arrival date (MAD), I constrained the dataset based on variability in the data during a given year to more accurately represent the MAD for these species. For each year, the hotspot points were divided into groups by biophysical region (Figure 3). For hotspots with >5 observations, I removed all observations that were >1 standard deviation from the MAD to remove outliers and better represent what the mean arrival was for that region. I used all observations for hotspots that had ≤5 points in that biophysical region. Only the earliest date was used for points that had multiple observations recorded in the same year on the same day, assuming that subsequent observations could be of the same individual.

Extracting climate data

Hotspot points were layered on top of the climatic maps for their corresponding year. Data from April and May were extracted to each hotspot point totaling six climatic parameters per point, plus elevation extracted from the DEM.

Modeling

Multivariate Linear Regression (MLR) was conducted in JMP statistical software (v 11, SAS Institute Inc., Cary, NC, USA) to determine which covariates showed significant correlations with JND. I used average mean, minimum, and maximum temperature for April, average mean, maximum temperature for May, elevation, latitude, and species as independent variables to explain JND. To refine Model 1, non-significant covariates were removed and the remaining variables were crossed to test for significant interactions between covariates.

As temperature was not included in any of the best fit MLR models, an additional MLR included the interactions between species and the six temperature parameters to directly observe any relationship between species and climate that may have been overlooked by the previous models.

IV. Results

Modeling

In Model 1, none of the temperature parameters were significant. Variance inflation factors (VIF) for the temperature covariates were all >10, indicating substantial autocorrelation among these variables (Table 1). Only species, latitude, and elevation explained a significant amount of variation in JND.

In Model 2, the temperature parameters were removed and the remaining covariates (species, latitude and elevation) and their interaction terms were included (Table 2; Figure 4). Again, only species, latitude, and elevation explained a significant amount of variation in JND.

Model 3 isolated the direct relationships between species and climate. None of the interaction terms were significant in explaining JND (Table 3).

V. Discussion & Conclusions

Explaining JND

Using the coefficients derived in Model 2, arrival date for both species was on average 2.9 days later with every degree of latitude (Table 2). The latitude range in Vermont is from approximately 42.75° to 45.00° N. As predicted by the model, there should roughly be a 6.6 days difference in JND in southern versus northern Vermont. The model also predicted that JND will be 0.0056 days later for every meter increase in elevation, or 5.6 days for every kilometer (elevation is in feet in the model with a coefficient of 0.0017 days per foot). The elevation at all the included hotspot points ranges from 26.82 to 1215.54 meters, so there is approximately 6.6 days difference between the highest and lowest elevations (Table 2). Lastly this model predicted that species also was a determinant of JND, with *V. solitarius* on average arriving 5.6 days earlier than *V. olivaceus* (Table 2). Lastly, Model 3 indicated that there were no significant interactions between species and temperature directly (Table 3). This suggests that despite the difference in migration distances between the two species, temperature is not affecting their arrival time differentially. The consistent insignificant correlation between temperature and JND does not reflect the findings of numerous other studies (Gordo & Sanz 2006; Hüppop & Hüppop 2003; Hurlbert& Zhongfei 2012; Kullberg et al. 2015; Swanson & Palmer 2009). This may be in part due to the statistical noise created by the low-resolution averaged temperature data and the inconsistency of the citizen science data. Additionally, the relatively limited time frame for analysis (8 years) may be insufficient to document trends.

Using citizen science data

In recent years, citizen science data has been examined as a possibility for data collection in peer-reviewed research, especially for ecological studies (Hurlbert & Zhongfei 2012). It allows for a substantial volume of data to be collected and compiled without formal funding or staffing. It is also an effective tool for outreach, inviting the general public to participate in conservation research. One of the most significant limitations of this project was the restricted number of years included. The data available from the eBird database does extend back several decades, but the number of observations submitted drastically increases over the past handful of years. Of the included hotspot points in this study, there were only 24 observations of *V. solitarius* and 20 observations of *V. olivaceus* in 2008, which increased to 87 and 110 by 2015 (Table 4). Data existed for these species prior to 2008, but the starting year was set to 2008 to maximize sample size. Most of the existing studies on this topic use datasets that encompass 40 years or more of migratory and climatic data, which allows for the observation of longer term trends (Hüppop & Hüppop 2003; Hurlbert & Zhongfei 2012; Swanson & Palmer 2009). Another weakness is the inconsistency of hotspot locations. There are very few locations that appear in even half of the years studied. Therefore the distribution of hotspot points varied from year to year, making comparisons inconsistent over time. Depending on the scope and sensitivity of the study, the strengths may or may not outweigh the limitations. For example, Hurlbert and Zhongfei were able to observe trends between temperature and mean arrival date using eBird observations across 10 years, 18 species, and the entire east coast the United States (2012). Citizen science may be a more practical tool when using a much broader scope and therefore a larger sample size.

Recommendations for future research

Despite evidence supporting the use of latitude and elevation to explain JND, it can only be applied to situations that span similar spatial and temporal scales. These two parameters do no change over time, and while they may influence climate, they will not reflect the climatic trends over long periods of time. It is crucial therefore to develop methods that compare climate directly to JND without using proxies such as elevation and latitude. Although the best way to quantify climate in terms of migration is still undetermined, utilizing a climatic dataset with greater spatial resolution will be greatly beneficial. The temperature data used in this study were monthly averages, and this simplifies climatic variation, especially during the onset of spring. Climatic datasets with daily values are currently being developed and will greatly contribute to migration research in the future.

There are several methods used in this study that deserve modification to further explore the best ways to use citizen science data. The data refinement process greatly decreased the ultimate number of sample points used in the models. Because of this and the spatial and temporal limits described above, this study was vulnerable to the effects of reduced sample size. There are two main suggestions that may prevent this in the future. First, including all eBird observation point types (ie not just hotspots) will greatly increase the sample size and improve the distribution across the study area. Secondly, creating a more sophisticated method for defining MAD may allow more of the points to remain in the dataset by using a less conservative outlier filter. These considerations encourage further exploration in how to use citizen science to its best potential.

The trends in bud burst phenology could prove to be a more direct determinant of arrival date. This crucial event controls when the lepidopteran eggs hatch and thus when the food supply for passerines is most abundant (Marra et al. 2005). If reliable and long term phenology data exist for the area of interest, it may be a valuable parameter to include in the analysis.

Lastly, the relationship between the climate at wintering grounds and departure date may be a more direct metric to investigate (Coppack & Both 2002; Lehikoinen et al. 2004). As discussed in the Literature Review, many species use climatic cues for departure. There may be a more significant and observable correlation between climate and migration timing at the onset of migration rather than at the end.

PART 2

I. Overview

There is much more to migration than meets the eye. It is nearly impossible to visualize because it takes place over continents, encompasses billions of individuals and changes slowly over centuries. And with a communication gap between the scientific community and the public, most groundbreaking knowledge either never reaches the general public or is published in journals in less than accessible language. However, there is a demand for communicating science in new ways and to make it more accessible and inclusive. One way to spread the interest, curiosity and investment in conserving migrating birds is through creative arts.

II. Literature Review

Over the past few decades, there has been an increase in using art to communicate science. Although commonly viewed as being separate disciplines and even separate sections of the brain, in reality science and art are very similar since they both entail opening the unknowns of the universe for all to see (Ede, 2000). Art has been used mostly in the fields of ecology and natural resources as it can tap into people's sense of place and motivate them to take action by connecting scientists to the greater community (Curtis, 2012).

The vast majority of Americans are considered scientifically illiterate (Sagan, 1996). Because science is critical to developing effective policy and management decisions, is the general lack of scientific understanding is a serious limit to addressing the critical environmental issues for society. Therefore, exploring the most powerful means of scientific communication is critical. There are three main ways that art can be successful at communicating science. First, art can induce wonder, inspiration and even spiritual stimulation in the viewer. This creates a personal connection between the viewer and the content. Second, art can change people's views, attitudes and actions through this connection. Finally, art can make the invisible visible, whether that is something microscopic or intercontinental or spanning centuries (Curtis, 2012). All of these contribute to making a lasting impact on people because emotion sticks in memory and forges a personal connection with the subject matter.

There are many examples of how scientists are translating their findings into art, such as Martin Krzywinski's *Circles of Life* (Krzywinski 2010) and Bryan James' *Species in Pieces* (James 2015). This innovative emerging form of scientific communication is extremely applicable to conservation because environmental issues are affected and addressed by personal choices and policy decisions. People only conserve what they cherish and value, and it is the scientist's responsibility to provide the justification for that value (Curtis 2012). If the personal value and the science are both present, art can connect and strengthen the two.

III. Methods

Paintings

The results and conclusions from Part 1 as well as the story of these two species were translated into two paintings on 60.96 cm x 91.44 cm (24 inch x 36 inch) canvas using acrylic paint and metal embellishments. The main intention of the paintings was to represent the species biology, climatic variables, and their interactions into one visual narrative. These were represented by both the specific details as well as overall themes in the paintings.

Survey

Once completed, the paintings were displayed for eight days in the Dudley H. Davis Student Center at The University of Vermont. The exhibit consisted of the two pieces, an overview plaque describing my project, an in-depth descriptive plaque explaining the intention and meaning behind all the components of the paintings, as well as surveys (see Appendix II), pencils, and a submission envelope. The survey consisted of 10 statements to which the participants responded on a scale from 1 to 5, 1 being “Strongly disagree”, 2 being “Disagree”, 3 being “Neutral”, 4 being “Agree”, and 5 being “Strongly agree”. There was open space for addition comments and an optional section asking for demographic information about the participant. This included occupation, area of study or work, and age (See Appendix II). An exhibit opening event was held on the second day to encourage visitors to complete the survey and ask questions. All surveys were collected at the end of the 8-day period.

IV. Results

Painting Interpretation

The specific details and the larger themes of the paintings were planned to represent particular aspects of this study’s findings and the life history of the species (Figure 5 A & B). The central features of the paintings are the clock faces which are meant to attract the viewer’s attention first. The clock faces depict the two species *V. olivaceus* and *V. solitarius*. The stained glass style represents the longevity and fragility of ecological processes. The wing edges of the birds trace the outline of their migration routes along the coast: *V. solitarius* migrates between the Northeast and the Gulf of Mexico while *V. olivaceus* migrates further south to South America for the winter. The hands of the clock hold a lot of what I ultimately concluded in my research. The minute hands have both a thermometer and mountain range. This signifies evidence I found for using elevation as a proxy for temperature when trying to explain arrival date. The hour hands draw the same connection except for latitude, represented by the compass. The time shown by the hands (1:21 for *V. olivaceus* and 1:12 for *V. solitarius*) correlates to the arrival of these species to the Burlington area last spring in Julian Days. The 121st day of the year is May 1st and the 112th day is April 22nd.

Moving outwards from the clock faces are features that illustrate both ancillary findings from this study and suggestions for future research (Figure 5 A & B). The petals surrounding the clock faces represent each of the four seasons, which are the underlying drivers of the need to migrate: red for autumn, white for winter, green for spring, and blue for summer. The gears were added to tie migration and the clocks, both being highly complex under the surface. The water drops signify the definite but difficult to predict relationship between climate and migration. They also represent precipitation which is one of the many other climatic parameters that could be examined in future studies in addition to temperature. The stray clock hands near the base signify the countless other parameters and factors that could be at play and have yet to be studied. The rows of feathers at the base illustrate the mean arrival date of that species to Vermont each spring from 2008 to 2015 across the state. Blues correspond with late April, greens with May, and yellows with the end of May. For example, the Northeast Kingdom is typically the last place they arrive.

Survey Results

During the eight days of the exhibit, forty-four people participated in the survey. Of those who provided optional demographic information, there was a wide range of ages (19 to 59 years old) and a broad variety of occupations and areas of study. Participants indicated a wide variety of backgrounds, including both environmental/biology disciplines and art.

Of the ten statements, the most diverse range of responses were from Statement 5 ("Before hearing about this exhibit, I knew of examples of art and science being used together.") and Statement 9 ("I was previously unaware of most of the information presented.") (Figure 6). The focal statements of the survey were numbers 2, 3, 4 and 8. Statement 2 ("I can see how scientific content was represented visually.") and Statement 8 ("Communicating science using art can help reach a wider audience.") both encapsulated the goals of the exhibit. Statement 3 ("I learned something about bird migration.") and Statement 4 ("I learned something about how climate change affects animal behavior.") reflect the intended outcome of the exhibit. In general there was a slightly stronger agreement for the statements about the integration of science and art as well as the communication of science through art than there was for participants gaining a better understanding of bird migration and the effects of climate change (Figure 7).

V. Discussion & Conclusions

Statements 5 and 9 were included to quantify the participants' previous knowledge about the subject matter and in using art and science collaboratively. These two statements received the most variable range of responses (standard deviations of 1.19 and 1.15 respectively) which reflected the group's wide range of disciplines; 21 of the participants indicated they had some background in ecology, biology, or other environmental field, 2 were trained in art, and 13 were in other fields. The other eight statements, which were assessing the participant's opinions and the effectiveness of the exhibit's ability to communicate and engage with the participant, received many more “Agree” and “Strongly Agree” responses. This reveals a general support for using science and art together and that this collaboration should be considered and encouraged as a means for reaching a broader audience.

There were more participants who strongly agreed with Statements 2 and 8 than for Statements 3 and 4, which indicates slightly more support for the purpose and goals of the exhibit than the perceived effectiveness of the exhibit itself. This may be due to the complicated and abstract nature of migration that proved difficult to translate into simple visuals. This should not however be seen as a limitation to the potential effectiveness of future science-art collaborations, especially for more abstract ecological processes.

Although just one small example, this exhibit accomplished its objective of reaching a broad audience and generating conversation and curiosity about these species, migration, and the impacts of climate change on the biosphere. The survey responses support the ability for art to both communicate science and teach people about ecological research. As this collaborative practice expands, it has great potential for changing perspectives and inspiring citizen engagement in wildlife conservation.

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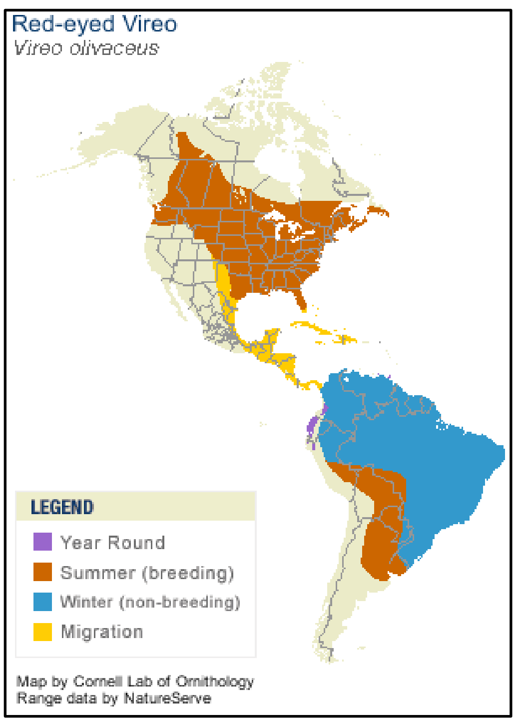
Appendix I: Figures & Tables

Figure 1. (A) Red-eyed Vireo (*Vireo olivaceus*). (B) Blue-headed Vireo (*Vireo solitarius*).
Source: Cornell Lab of Ornithology – All About Birds.



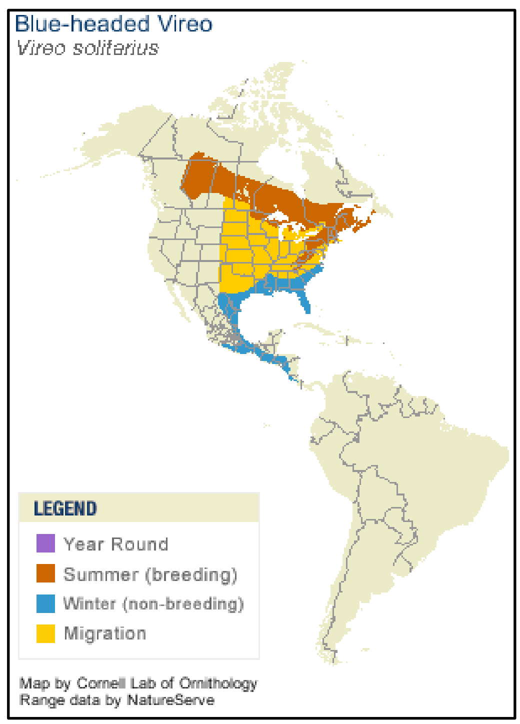


Figure 2. (A) Range of Red-eyed Vireo and (B) range of Blue-headed Vireo.
Source: Cornell Lab of Ornithology – All About Birds.

Figure 3. The biophysical regions of Vermont are defined based on patterns in geology, climate, topography, natural communities, water resources, and historical human use (Thompson & Sorenson 2000).

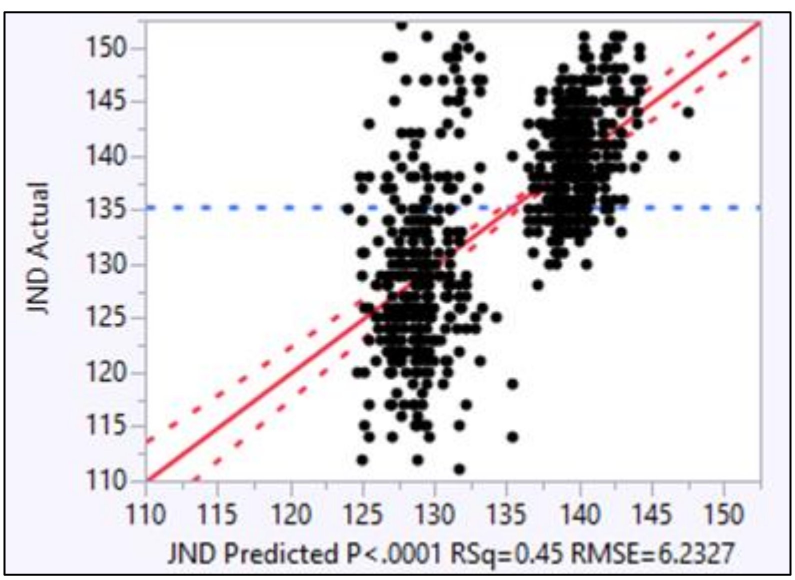
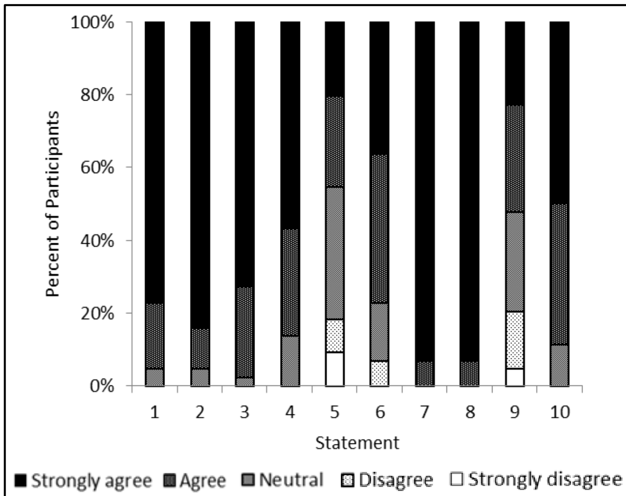


Figure 4. Model 2 uses species, latitude, elevation, and their interactions to explain variation in Julian Number Day in a multivariate linear regression.

Figure 5. Paintings of (A) Red-eyed Vireo (*Vireo olivaceus*) and (B) Blue-headed Vireo (*Vireo solitarius*).



1. I understand the scientific content represented in this exhibit.
2. I can see how scientific content was represented visually.
3. I learned something about bird migration.
4. I learned something about how climate change affects animal behavior.
5. I was previously unaware of most of the information presented.
6. I have personal value in birds.
7. Art and science can be used collaboratively.
8. Communicating science using art can help reach a wider audience.
9. Before hearing about this exhibit, I knew of examples of art and science being used together.
10. Because of this exhibit, I would like to learn more about the subject matter.

Figure 6. Percent of participant (n = 44) agreement with 10 statements on the survey ranging from "Strongly agree" to "Strongly disagree".

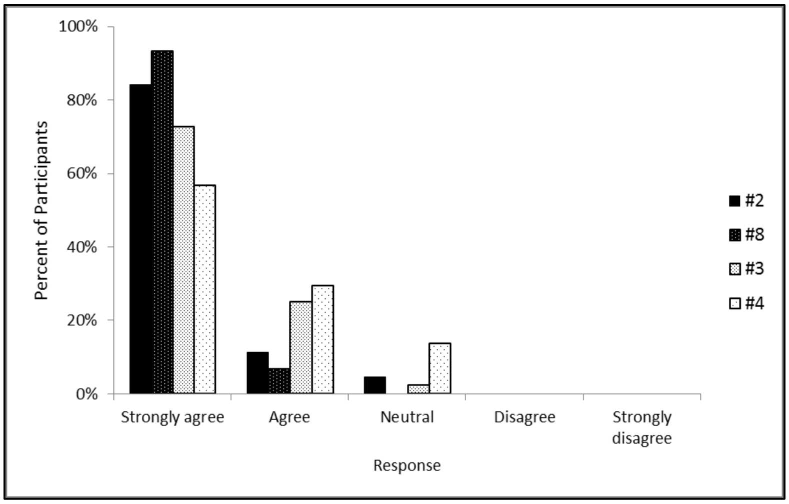


Figure 7. Distribution of participant (n = 44) agreement with statements about the goals of the exhibit (Statements #2 and #8) and the effectiveness of the exhibit (Statements #3 and #4).

Table 1. In Model 1, all parameters were included in a multivariate linear regression (n=843, $r^2 = 0.4679$, mean = 135.32, $p < 0.001$)

Variable	Estimate	P value	VIF
Species	-5.5722	<0.001	1.0315
Latitude	3.1450	<0.001	1.1875
Elevation	0.0009	0.0305	1.6351
Tmax April	-34.0767	0.2781	108862.0900
Tmax May	24.6851	0.4117	143791.2800
Tmean April	68.6084	0.2751	266041.3400
Tmean May	-49.9690	0.4059	358168.9000
Tmin April	-34.6313	0.2707	53202.6580
Tmin May	24.7502	0.4102	73917.0960

Table 2. In Model 2, the species, latitude and elevation along with their interactions were included in a MLR (n = 843, $r^2 = 0.4519$, mean = 135.32, $p < 0.001$).

Variable	Estimate	P value
Species	-5.5719	<0.001
Latitude	2.9350	<0.001
Elevation	0.0017	<0.001
Species*Latitude*Elevation	-0.0003	0.5867
Species*Latitude	0.3590	0.4005
Species*Elevation	<0.001	0.8957
Latitude*Elevation	<0.001	0.3107

Table 3. In Model 3, the interactions between species and the six temperature parameters were included in a MLR (n = 843, r2 = 0.462845, mean = 135.32, p < 0.001).

Variable	Estimate	P vlaue
Species * Tmax May	39.16907	**0.2021**
Species * Tmax April	-45.13097	**0.1636**
Species * Tmean May	-79.07184	**0.1978**
Species * Tmean April	88.46628	**0.1723**
Speceis * Tmin May	38.84872	**0.2056**
Species * Tmin April	-43.49485	**0.1797**

Table 4. The number of hotspots included in the sample each year from 2008 to 2105 for both *V. solitarius* (BHVI) and *V. olivaceus* (REVI).

Year	BHVI	REVI	Total
2008	24	20	**44**
2009	25	33	**58**
2010	31	39	**70**
2011	28	52	**80**
2012	42	78	**120**
2013	49	79	**128**
2014	64	82	**146**
2015	87	110	**197**
Total	**350**	**493**	**843**

Appendix II

Survey

Thank you for choosing to share your thoughts about my thesis exhibit. Your opinions and input is extremely valuable to me. Your answers will remain anonymous and will be used in my final thesis. Participation implies your consent for me to use your answers in my analyses. Thank you again for your time and participation. Feel free to contact me with any questions or comments at jmailhot@uvm.edu.

Please rate the following statements: 1 being strongly disagree, 3 being neutral, 5 being strongly agree.

1. I understand the scientific content represented in this exhibit.
   1 2 3 4 5
2. I can see how scientific content was represented visually.
   1 2 3 4 5
3. I learned something about bird migration.
   1 2 3 4 5
4. I learned something about how climate change affects animal behavior.
   1 2 3 4 5
5. I was previously unaware of most of the information presented.
   1 2 3 4 5
6. I have personal value in birds.
   1 2 3 4 5
7. Art and science can be used collaboratively.
   1 2 3 4 5
8. Communicating science using art can help reach a wider audience.
   1 2 3 4 5
9. Before hearing about this exhibit, I knew of examples of art and science being used together.
   1 2 3 4 5
10. Because of this exhibit, I would like to learn more about the subject matter.
   1 2 3 4 5

Other comments:

Optional demographic information:

Occupation: __Undergraduate student __ Graduate student

__ Faculty __Other UVM employee __ Other

Area of study/work: ____

Age: ______