Spatial Responses to Climate Change in a Long-Distance Migratory Songbird: the Scarlet Tanager (*Piranga olivacea*)

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Abstract

Climate change is threatening the populations of many species with extinction. Migratory species whose breeding ranges are located in areas of fast-paced change are at heightened risk because their ability to replace themselves in the population is the most threatened portion of the annual cycle. We propose an assessment of the spatial response to climate change of such a species, the Scarlet Tanager (*Piranga olivacea*). *P. olivacea* migrate to the northern regions of North America, where rapid climate change may threaten the species' suitability to their historical breeding areas. To test whether *P. olivacea* are responding spatially to climate change, we will use a two-pronged approach looking at 1) occurrence and 2) morphological change from across their breeding range over time. First, we will assess spatial responses to climate change by comparing historical breeding occurrence and climate data (March-August, ca. 70-50 years ago; 1950-1970), to current occurrence data (years 2000-2020), to build a forecast of potential future breeding distribution for this species using Maxent software. Breeding season occurrence data for historical and current time periods will be sourced from museum records, and will be matched with environmental data (i.e., temperature, precipitation, land cover). Recent research has supported that migratory birds are growing longer wings in response to climate change, presumably under selection pressure to support improved flight efficiency for migrating longer distances to access appropriate environmental conditions for breeding. We will assess morphological changes over time in breeding *P. olivacea* in response to predictions under climate change hypotheses by measuring museum specimens from the American Museum of Natural History and the Louisiana State University Museum of Natural Science. We intend to infer whether *P. olivacea* possesses adequate adaptive potential to keep pace with relevant climate change metrics, and more broadly whether climate change is driving selection on morphology to reach a more northern breeding distribution for this species. If the historical distribution is explained by climate variables but *P. olivacea* has not shifted its breeding range or exhibited morphological shifts, this may be evidence of low adaptive capacity. Climate, morphological and occurrence data will be analyzed to determine the suitability of *P. olivacea* in its current breeding range, as well as alternative responses including shifts in the species' reproductive windows. Our data will include bill length, mass, and hand-wing index variables for morphological analyses, while precipitation, temperature, and land cover will be included in the environmental datasets.

Introduction

In the 21st century, climate change is threatening the populations of many species with extinction (Parmesan and Yohe 2003). Migratory species, some of whose breeding ranges are in poleward areas of fast-paced change, are at risk (Møller et al. 2008, Sander et al. 2020). Historical dispersal and vicariance at northern latitudes contribute to genomic structure that can limit current adaptive genetic diversity to impede responses to environmental change via natural selection (Wilson et al. 2021). At a proximate level, warming breeding grounds are unlikely to contribute to increased reproductive output in long-distance avian migrants through increased food availability or re-nesting (Saalfeld et al. 2021). Taken together, research testing hypotheses about how migratory species respond to climate change is needed to improve our understanding of resilience in wildlife populations.

In general, when confronted with anthropogenic change, species can respond in one of three ways: 1) by going extinct, 2) surviving by shifting their geographic range, or 3) evolving in place. There are several examples of species becoming endangered or going extinct following environmental change, including from processes like the elevator to extinction (Freeman et al. 2018), Allee effects (Nagel et al. 2021), and genomic erosion (Díez-del-Molino et al. 2018). Shifts in geographic ranges have been observed and tend to appear where climate change velocity is fastest (Poloczanska et al. 2013). There is some evidence that some birds have plasticity in morphological traits to accommodate enhanced dispersal abilities to shift ranges (Weeks et al. 2019), but phenotypic evolution may be constrained by allometry (Fasanelli et al. 2021). Assessing the probability of different outcomes of range dynamics under climate change requires a deep understanding of landscape ecology, climate and land use change (hereafter anthropogenic change), and species specific traits (Radosavljevic and Anderson 2014, Hallman and Robinson 2020).

Dramatic changes in climate over the remainder of this century are expected with many species likely unable to survive in the areas they presently occupy (Sax et al. 2013, Ceballos et al. 2015). Forecasts of spatial responses of populations to anthropogenic change is likely to be more reliable when we understand how populations have responded to past changes (Moritz and Agudo 2013). To this end, there is a rich knowledge of avian distributions and species-habitat relationships in North America that can be used to evaluate how migratory birds are responding to anthropogenic change by comparing historical to current distributions in light of documented climate and land use change. Here, we propose using data from publicly funded databases that gather information on occurrence, abundance, and reproduction to inform on migratory bird spatial responses to anthropogenic change on their breeding grounds.

We address the applied question of whether migratory bird species show evidence of adaptive potential to anthropogenic change by testing a series of hypotheses. Our first hypothesis is that the location of the historical breeding range core is no longer optimal because environmental conditions on the breeding range have changed so much. If so, we predict that if habitat needs have not changed, bird locations will be correlated with the same environmental variables across three time periods: 1900-1920, 1950-1970, 2000-2020 (a time series with available data from public data bases). Alternatively, if habitat needs have changed over time,

bird locations will be correlated with different environmental variables over time. If so, the breeding range core will move with the values of environmental variables that their locations are correlated with. A second alternative is that if habitat needs have changed in step with environmental change, the location of the breeding range core will be consistent over time. If habitat needs have stayed the same, but the core distribution has not changed, populations will have declined. A third alternative is that if habitat needs have changed in step with environmental change, or the location of the core distribution has shifted, populations will be the same after accounting for available habitat.

As dispersal limitation is a core part in distinguishing the realized niche that can limit range shifts despite available habitat (Palma et al. 2020), we also had several hypotheses concerning morphology. First, morphology of migratory birds is a product of resource availability, heat dissipation, and migratory distance. If so, if temperatures on the breeding grounds have increased over time, we expect individuals to have lower body mass:size ratios to increase heat dissipation. We expect mass to decrease and tarsus length and bill size to increase over time. Alternatively, individuals may take advantage of microhabitat refugia for behavioral thermoregulation by taking breaks from breeding activities to bathe, pant, or simply be in the shade. We do not plan to test this alternative. However, if the location of the core breeding range has shifted, we expect that individuals will have longer wing lengths to facilitate increased aerodynamic efficiency over a greater migratory distance. If resource availability has declined over time due to the impact of changing environments on prey, we predict that the mass of individuals will decline over time. We do not intend to test this hypothesis because it would require a different spatial modeling approach, a comparative approach across multiple different species that differ in the effect of environmental change, or an approach that includes measurements of prey availability over time that is outside of the scope of the proposed research. Even in long-distance migrants, habitat availability and morphology can limit how far individuals will be able to shift their breeding ranges in response to climate changes. If species do not shift their habitat requirements over time, we predict that there is a northern limit to their breeding range associated with shifts between ecoregions that currently delineate the northern edge of breeding ranges. If species demonstrate longer wings in response to increased migration distance to further north core breeding distributions, we expect a limit to how long their wings could get to accommodate increased migratory distances.

We can also test hypotheses about whether migratory birds can shift the timing of the onset of breeding to appropriately match phenological changes in habitat and food resources necessary for successful reproduction. Here we hypothesize that the timing of the onset of breeding is dependent upon environmental conditions on the breeding grounds. If species have adaptive potential to respond to the impacts of climate change, the timing of breeding will shift in response to environmental deviations. If there is an increase in weather anomalies in the spring such as cold snaps (e.g., Shipley et al. 2020) or anomalous drought or increases in precipitation (calculated using the Standard Anomaly Index), selection will favor later breeding individuals. We predict that birds will delay the onset of breeding over time. Alternatively, warmer temperatures could accelerate ideal reproductive conditions in the spring and individuals could have earlier onset of breeding to match potentially earlier peak food resources with fledgling dates. A second alternative is that if environmental conditions on the breeding grounds change and populations do not shift the timing of the onset of breeding, their populations will decline over time.

We propose an assessment of the spatial, morphological, and reproductive responses to climate and land use change of a long-distance migratory species that breeds in North America, the Scarlet Tanager (*Piranga olivacea*). *P. olivacea* migrate to the northern regions of North

America (Mowbray 2020), where rapid climate change may threaten the species' suitability to their historical breeding areas. We will assess spatial responses to climate change by comparing historical breeding occurrence and climate data (March-August, ca. 70-50 years ago; 1950-1970), to current occurrence data (years 2000-2020), to build a forecast of potential future breeding distribution for this species. Breeding season occurrence data for historical and current time periods will be sourced from museum records from www.gbif.org, and will be matched with environmental data (i.e., temperature, precipitation, land cover). We will assess morphological changes over time in breeding *P. olivacea* in response to predictions under climate change hypotheses by measuring museum specimens from the American Museum of Natural History and the Louisiana State University Museum of Natural Science. We intend to infer whether *P. olivacea* possesses adequate adaptive potential to keep pace with relevant climate change metrics, and more broadly whether climate change is driving selection on morphology to reach a more northern breeding distribution for this species. If the historical distribution is explained by climate variables but *P. olivacea* has not shifted its breeding range or exhibited morphological shifts, this may be evidence of low adaptive capacity. Climate, morphological and occurrence data will be analyzed to determine the suitability of *P. olivacea* in its current breeding range, as well as alternative responses including shifts in the species' reproductive windows. Despite being the longest-distance migrant in the *Piranga* (Mowbray, 2020), habitat availability and morphology will limit how far *P. olivacea* can shift their breeding range in response to climate changes. If *P. olivacea* do not shift their habitat requirements over time, we predict that there is a northern limit to their breeding range associated with the shift from mixed wood plains to mixed wood shield ecoregions that currently delineate the northern edge of their breeding range (Sibley 2009, Mowbray 2020). We predict that *P. olivacea* will have the longest size-adjusted wing length in a comparison across the Thraupidae.

Methods

Study design

Question	Hypothesis	Sampling plan	Analysis Plan	Rationale for deciding the sensitivity of the test for confirming or disconfirming the hypothesis	Interpretation given different outcomes	Theory that could be shown wrong by the outcomes
How is climate change and changing environmental conditions affecting the habitat and morphological evolution of <i>P. olivacea</i> ?	The location of the historical breeding range core is no longer optimal because environmental conditions on the breeding range have changed so much.	<i>Environmental data</i> We will collect environmental data from four distinct time periods: 1900-1920, 1950-1970, 2000-2020, and 2061-2080. Specifically, we will assess correlations of <i>P. olivacea</i> occurrences with temperature (min, max, mean), precipitation (ave), and land cover for every month of the breeding season (April-September). As breeding locations for <i>P. olivacea</i> are in North America, monthly temperature and rainfall data will be sourced from the National Center for Environmental Prediction for 1950-2020 via the R package RNCEP (Kemp et al., 2015). For the 1900-1920 time period, we will use the monthly temperature and precipitation spatial datasets created by MacDonald et al. (2020). We will use WorldClim future climate data to project the 2000-2020 distribution model to 2061-2080 (https://www.worldclim.org/data/cmip6/cmip6climate.html). We will identify temperature and rainfall weather anomalies from the NCEP data from 1966-2020 following Shipley et al. (2020), and will gather	To assess hypothesis 1 (location of the historical breeding range core), we plan to conduct monthly MaxEnt species distribution models for April-September for each time period (1900-1920, 1950-1970, 2000-2020) using MaxEnt software v.3.4.4 (Phillips et al., 2018). We will present the values of environmental variables with the highest correlations with <i>P. olivacea</i> occurrence data and then compare the location of the highest probability of occurrence between time periods using mapping tools within the R statistical computing program (R Core Team, 2020). We will follow the methods of Arnold (2018) to estimate population growth rates from bird banding data	We will contrast 6 different standard measures of goodness of fit to confirm or disconfirm the hypothesis. The multitude of metrics are meant to provide support for our conclusions given criticisms of each. We will use AUC values and root mean square error (RMSE) to determine model fit, in addition to exploring Kappa and True Skill Statistic as potential alternatives. We will use percent contribution and permutation importance to distinguish the importance of each variable in distribution models. The metrics are described here: <i>Area Under the Curve (AUC) Values</i> - These values will be used to determine model fit for each species distribution model. Higher AUC values reflect better fit distribution models that will be used to measure correlations between occurrence and habitat. <i>Percent contribution</i> - The proportional contribution of	P1: If the habitat needs of <i>P. olivacea</i> have not changed, their locations will be correlated with the same environmental variables across three time periods: 1900-1920, 1950-1970, 2000-2020. Alternative 1: If the habitat needs of <i>P. olivacea</i> have changed over time, their locations will be correlated with different environmental variables over time. P2: The breeding range core will move with the values of environmental variables that their locations are correlated with.	Here we are testing whether climate change has caused changes to the suitability of the historical breeding range of <i>P. olivacea</i> .

	<p>drought information from the TerraClimate data set (https://developers.google.com/earth-engine/datasets/catalog/IDAHO_EPSCOR_TERRACLIMATE). For land cover data we will use the North American Land Change Monitoring System's data layer from 2015 as an approximation of land cover for the entire 2000-2020 time period (access here: https://www.mrlc.gov/data?f%5B0%5D=category%3Aland%20cover&f%5B1%5D=region%3Anorth%20america). For the 1900-1920 and 1950-1970 time periods we will use the Land-Use Harmonization 2 (LUH2) data set of annual land-use transition mapping (Hurtt et al., 2006). Both land use datasets will be used to distinguish agriculture, urban, rural, and forested land in addition to forest type or ecoregion. We plan to assess the LUH2 data and another global future land use model (LU; Chen et al., 2020) in combination with WorldClim future temperature and precipitation estimates to forecast future distributions of <i>P. olivacea</i>. All environmental data sources are 30m resolution.</p> <p><i>P. olivacea</i> occurrence data We will use occurrence data sourced from www.gbif.org.</p> <p><i>P. olivacea</i> population estimates We will use data from bird banding stations sourced from the United</p>	<p>from 1900-2020.</p>	<p>each explanatory variable in distribution models are assigned according to the changes in model gain when each layer is modified.</p> <p><i>Permutation importance</i> - This is a second assessment of importance calculated by randomly permuting the values within each explanatory variable. Permuted environmental data allow comparisons between AUC models and permutation analyses distinguish the influence of environmental variables from one another, allowing for the inclusion of relevant variables regardless of correlation between them.</p> <p><i>Root mean square error (RMSE)</i> - These values will be used as a second performance measure of distribution models. Lower RMSE values reflect better fit models.</p> <p><i>Kappa values</i> - These values will be used in addition to AUC. Higher Kappa values reflect better fit distribution models.</p> <p><i>True Skills Statistic (TSS) Values</i> - These values will be used in addition to AUC and Kappa. Higher TSS values reflect better fit distribution models.</p> <p>For best practices in species distribution modelling, it is important to try and collect samples from the entire range</p>	<p>Alternative 2: If the habitat needs of <i>P. olivacea</i> have changed in step with environmental change, the location of the breeding range core will be consistent over time.</p> <p>P3: If habitat needs have stayed the same, but the core distribution has not changed, <i>P. olivacea</i> populations will have declined.</p> <p>Alternative 3: If habitat needs have changed in step with environmental change, or the location of the core distribution has shifted, <i>P. olivacea</i> populations will be the same after accounting for available habitat.</p>	
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		<p>States Geological Survey's Bird Banding Laboratory (serves both Canada and the United States) to estimate population trends.</p>		<p>of environmental variables experienced by the taxon of interest. Samples originating from smaller areas or biased sampling can contribute to model overfitting to a narrow range of environmental values which is a major problem in species distribution modeling. Thus, we aim to thoroughly sample occurrence data by using the www.gbif.org source which has been contributed to from museums collecting across <i>P. olivacea</i>'s breeding range. Likewise, we intend to measure specimens from two of the largest collections of <i>P. olivacea</i> specimens in North America, the American Museum of Natural History and the Louisiana Museum of Natural Science. Although these collections are not yet digitized, we believe that they will comprise individuals from across the breeding range and for each time period (1900-1920, 1960-1970, 2000-2020). If they do not, we intend to supplement our dataset by measuring specimens at the Royal Ontario Museum in Canada and/or the Smithsonian National Museum of Natural History in the United States to meet minimum sample sizes.</p> <p>We plan to use all available occurrence data from www.gbif.org. To follow best</p>		
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				<p>practices for species distribution modelling, we will omit months with fewer than 3 observations (Aubry et al., 2017; Pearson et al., 2007).</p> <p>Because we are using previously collected data from online repositories, there may be some missing data. We plan to omit months, years, or pixels without data from our analysis but anticipate that the dataset will be robust enough to detect patterns if they exist due to the amount of time being assessed.</p> <p>We plan to use all available capture data of <i>P. olivacea</i> from bird banding stations within each of the three time periods being assessed with core distribution data (1900-1920, 1950-1970, 2000-2020).</p>		
(see above)	<p>Despite being the longest-distance migrant in the <i>Piranga</i> (Mowbray, 2020), habitat availability and morphology will limit how far <i>P. olivacea</i> can shift their breeding range in response to</p>	<p>(see above, and below)</p> <p><i>P. olivacea</i> <i>morphological change</i> We will document morphological change by measuring museum specimens of <i>P. olivacea</i> from each time period from the American Museum of Natural History and the Louisiana Museum of Natural Science. We will measure the following morphologies: bill length, bill width, bill depth, wing chord length, tail length, tarsus length following MacPherson et al. (2021). We will record mass data from specimen tags whenever they are available.</p>	<p>To assess hypothesis 4 (how far <i>P. olivacea</i> can shift their breeding range), we will use MaxEnt to forecast <i>P. olivacea</i> range into the future using predicted temperature, precipitation and land cover data sets. We will use phylogenetic general least squares (PGLS) to assess the wing chord length of <i>P. olivacea</i> in comparison to other Thraupidae species using the ‘caper’</p>	<p>(see above, and below)</p> <p>We use the standard alpha = 0.05 to assess whether <i>P. olivacea</i> has the longest size-adjusted wing length.</p> <p>We plan to only use morphological measurement data from Thraupidae species available at Birds of the World online (only one set of measurements per species).</p>	<p>P8: If <i>P. olivacea</i> do not shift their habitat requirements over time, we predict that there is a northern limit to their breeding range associated with the shift from mixedwood plains to mixedwood shield ecoregions that currently delineate the northern edge of their breeding</p>	<p>Here we are testing whether habitat availability and morphological plasticity both matter for predicting responses to climate change.</p>

	climate changes.	<p><i>Thraupidae phylogeny</i> We will use the most recent molecular phylogeny of the Tanager family Thraupidae (Burns et al., 2014).</p> <p><i>Morphometrics of Thraupidae species</i> We will use average measurements of wing chord length, tarsus length and mass for all Thraupidae species that are available from Birds of the World online (2021).</p>	package in R (Orme et al., 2013).		<p>range (Mowbray, 2020; Sibley, 2009).</p> <p>P9: If <i>P. olivacea</i> demonstrate longer wings in response to increased migration distance to further north core breeding distributions, we expect a limit to how long their wings could get to accommodate increased migratory distances. We predict that <i>P. olivacea</i> will have the longest size-adjusted wing length in a comparison across the Thraupidae.</p>	
	Morphology of migratory birds is a product of resource availability, heat dissipation, and migratory distance.	<p>(see above) <i>Principal Component Analysis Scores</i> - The authors will perform a principal components analysis to combine the three bill measurements into indices of bill volume and shape. This will be done for all individuals and then PC1 and PC2 scores will be calculated for each individual.</p> <p><i>Hand-wing Index (HWI)</i> - A measure of the shape of the wing that can be obtained from round museum specimens. High HWI values reflect more elongated wings</p>	To assess hypothesis 2 (morphology), we plan to use linear models to assess the relationship between maximum monthly temperature and mass:body size ratios. We will use AIC to select the models with the highest explanatory amongst those with different body size variables. The different body size estimates could be comprised of wing chord length,	We use the standard alpha = 0.05 in linear models.	P4: If temperatures on the breeding grounds have increased over time, we expect individual <i>P. olivacea</i> to have lower body mass:size ratios to increase heat dissipation. We expect mass to decrease and tarsus length and bill size to increase over time.	Here we are testing whether wing length is positively correlated with migratory distance in the instance that the breeding range is shifting further

		<p>and indicate higher flight performance than low HWI values. $HWI = ((WL-SL)/WL) \times 100$ where WL = wing chord length from the carpal joint to the tip of the longest primary feather, and SL = the secondary length measured from the carpal joint to the tip of the first secondary feather (Claramunt & Wright, 2017).</p> <p><i>Body Size</i> - We will divide mass (as listed on specimen tags) by tarsus length as an estimate of body size for each individual <i>P. olivacea</i>.</p> <p>For documenting morphological changes among time periods (1900-1920, 1950-1970, 2000-2020) in <i>P. olivacea</i>, we will use the sample size of <i>P. olivacea</i> from Weeks et al. (Weeks et al., 2020; Supporting Information) of at least 119 individuals per time period.</p>	<p>tarsus length, the first principal component score of the combination of three bill morphological measurements (bill length, bill width, bill depth) or some combination of these. Because wing chord length has been shown to increase over time in another study (Weeks et al., 2020), we will use a linear model to assess whether changes in the location of the core breeding range over time are correlated with average wing chord length measured from museum specimens.</p>		<p>Alternative 4: Alternatively, individual <i>P. olivacea</i> may take advantage of microhabitat refugia for behavioral thermoregulation by taking breaks from breeding activities to bathe, pant, or simply be in the shade. We do not plan to test this alternative.</p> <p>P5: If the location of the core breeding range has shifted, we expect that individual <i>P. olivacea</i> will have longer wing lengths to facilitate increased aerodynamic efficiency over a greater migratory distance.</p> <p>P6: If resource availability has declined over time due to the impact of changing environments on prey, we predict that the mass of individual <i>P. olivacea</i> will decline</p>	<p>north (therefore increasing migratory distance within a species).</p> <p>We are also testing whether heat dissipation is a detectable part of this pattern which is important for physiological processes and in the face of warming temperatures.</p>
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					over time. We do not intend to test this hypothesis because it would require a different spatial modeling approach, a comparative approach across multiple different species that differ in the effect of environmental change, or an approach that includes measurements of prey availability over time that is outside of the scope of the proposed research.	
Does <i>P. olivacea</i> display evidence of adaptive potential to respond spatially to climate change?	The timing of the onset of breeding is dependent upon environmental conditions on the breeding grounds. If <i>P. olivacea</i> have adaptive potential to respond to the impacts of climate change, the timing of breeding will	<i>Breeding season onset</i> - The authors will also extract dates from the Breeding Bird Survey data to determine the breeding season onset. The breeding season onset will be determined as the yearly mean first egg date from Breeding Bird Survey data. This may be back calculated from other observed breeding behaviors (e.g., observations of a nest fledging or parents feeding fledglings) and estimates of the duration of stages of chick-rearing (e.g., incubation duration, nestling duration). <i>Weather anomalies</i> - We will identify the timing of cold snaps for the months of April-July from 1966-	To assess hypothesis 3 (timing of the onset of breeding), we will follow Haest et al. (2018) to perform a spatially explicit time-window analysis of the effect of temperature variables from the NCEP dataset with Breeding Bird Survey data on the onset of breeding from 1966-2020. We will iteratively assess the linear model comparison of spatially explicit onset of breeding with the spatially explicit model of population growth rates	We use the standard alpha = 0.05 in linear models.	P7: If there is an increase in weather anomalies in the spring such as cold snaps (e.g., Shipley et al., 2020) or anomalous drought or increases in precipitation (calculated using the Standard Anomaly Index), selection will favour later breeding individuals. We predict that <i>P. olivacea</i> will delay the onset of breeding over time.	Here we are testing whether changes to the onset of breeding are correlated with environmental conditions (i.e., monthly min., max., ave.) or may be correlated with

	<p>shift in response to environmental deviations.</p>	<p>2020 using NCEP data and following Shipley et al. (2020). We will identify anomalous heavy rainfall events in a similar fashion by comparing daily precipitation estimates and calculating 3-d rolling averages to test for precipitation trends across the entire time period of 1966-2020. Drought data is integrated across time (i.e., you don't have drought for just one day) and is an interpreted dataset from WorldClim and CRU Ts4.0 climate data and reanalysis time windows.</p> <p><i>Population growth rates</i> - population growth rates will be calculated following Arnold (2018).</p> <p><i>Standard Anomaly Index (SAI)</i> - This will be used to calculate the negative and positive anomalies of rainfall fluctuations in the breeding range. The index is calculated as $Z=(X_i-X_{bar})/S$ where Z is the standardized rainfall anomaly, X_i is the typical monthly rainfall, X_{bar} is the mean of typical monthly rainfall, and S is the standard deviation of the typical monthly rainfall.</p> <p>For estimating <i>P. olivacea</i> population growth rates we will aim for at least 120,000 individuals for each 20-year time period (following Arnold, 2018).</p> <p>For estimating the onset of the breeding season we will use the minimum sample size recorded in Haest et al.'s (2018) estimate of</p>	<p>to determine if the timing of breeding onset is correlated with annual population growth rates from 1966-2020.</p>		<p>Alternative 7a: Alternatively, warmer temperatures could accelerate ideal reproductive conditions in the spring and <i>P. olivacea</i> could have earlier onset of breeding to match potentially earlier peak food resources with fledgling dates.</p> <p>Alternative 7b: If environmental conditions on the breeding grounds change and <i>P. olivacea</i> do not shift the timing of the onset of breeding, their populations will decline over time.</p>	<p>anomalous weather.</p>
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		migration phenology of 26 individuals per year.				
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Guidance Notes

- **Question:** articulate each research question being addressed in one sentence.
- **Hypothesis:** where applicable, a prediction arising from the research question, stated in terms of specific variables rather than concepts. Where the testability of one or more hypotheses depends on the verification of auxiliary assumptions (such as positive controls, tests of intervention fidelity, manipulation checks, or any other quality checks), any tests of such assumptions should be listed as hypotheses. Stage 1 proposals that do not seek to test hypotheses can ignore or delete this column.
- **Sampling plan:** For proposals using inferential statistics, the details of the statistical sampling plan for the specific hypothesis (e.g power analysis, Bayes Factor Design Analysis, ROPE etc). For proposals that do not use inferential statistics, include a description and justification of the sample size.
- **Analysis plan:** For hypothesis-driven studies, the specific test(s) that will confirm or disconfirm the hypothesis. For non-hypothesis-driven studies, the test(s) that will answer the research question.
- **Rationale for deciding the sensitivity of the test for confirming or disconfirming the hypothesis:** For hypothesis-driven studies that employ inferential statistics, an explanation of how the authors determined a relevant effect size for statistical power analysis, equivalence testing, Bayes factors, or other approach.
- **Interpretation given different outcomes:** A prospective interpretation of different potential outcomes, making clear which outcomes would confirm or disconfirm the hypothesis.
- **Theory that could be shown wrong by the outcomes:** Where the proposal is testing a theory, make clear what theory could be shown to be wrong, incomplete, or otherwise inadequate by the outcomes of the research.

Open materials

All data collected as a part of this research could be available online at <https://github.com/mmacphe/Scarlet-Tanager-Project> and a permanent open source repository appropriate for each type of information will be submitted to OSF or zenodo depending upon the data type.

Author Contributions

Lily Donzeiser: concept = hypothesis development; writing = literature review, main author.

Maggie MacPherson: writing = literature review, minimal writing, editing; training = teaching writing skills, suggesting statistical analyses, teaching data collection and analytical skills.

Conflict of Interest Disclosure

The authors declare that they have no conflicts of interest. The authors have no financial conflict of interest with the content of this article. In the last year, the second author has published with Corina Logan and Dieter Lukas who are both Recommenders at PCI Ecology and Corina Logan is on the Managing Board at PCI Ecology and Peer Community in Registered Reports.

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