Avian Demographic Response to Climate Change:

A Multi-Species and Multi-Landscape Approach to Synthesizing Risk Factors

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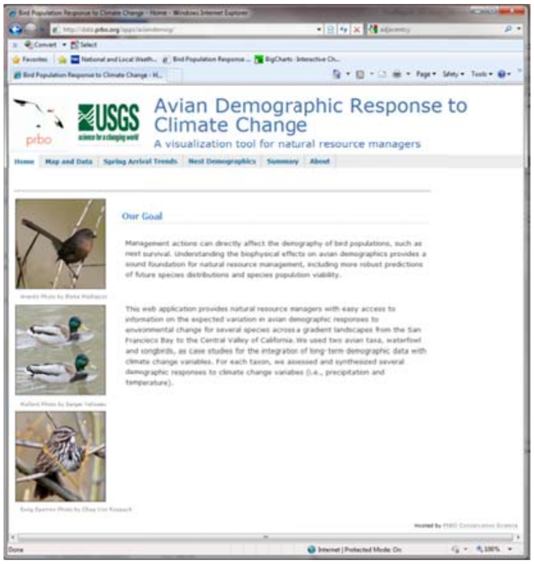
Bird photographs on cover provided by Josh Ackerman, Bob McLandress, and PRBO Conservation Science.

Executive Summary

Study Objectives

- Understanding the biophysical effects on avian demographics provides a sound foundation for natural resource management, including more robust predictions of future species distributions and species population viability.
- We evaluated how avian demographic parameters have been influenced by climate variables (i.e., temperature and precipitation) in the past using several long-term datasets on two main guilds of birds, waterfowl and songbirds, across a gradient of habitats from the Coast Range, through the San Francisco Bay, and into the Central Valley of California.
- We also evaluated how avian demographic parameters are likely to respond to future climate change scenarios.
- We provide a web-based tool to assist natural resource managers with understanding the potential future impacts of climate change and the specific effects of environmental variables.



Avian Demographic Response to Climate Change

A visualization tool for natural resource managers

Our Goal

Management actions can directly affect the demography of bird populations, such as nest survival. Understanding the biophysical effects on avian demographics provides a sound foundation for natural resource management, including more robust predictions of future species distributions and species population viability.

This web application provides natural resource managers with easy access to information on the expected variation in avian demographic responses to environmental change for several species across a gradient landscapes from the San Francisco Bay to the Central Valley of California. We used two avian taxa, waterfowl and songbirds, as case studies for the integration of long-term demographic data with climate change variables. For each taxon, we assessed and synthesized several demographic responses to climate change variabes (i.e., precipitation and temperature).

Study Results

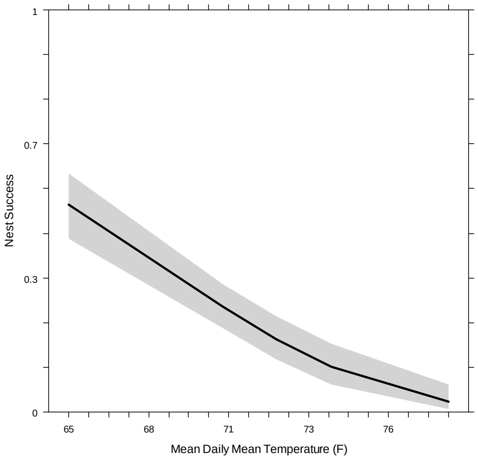
Web-Based Application for Natural Resource Managers

- We created a web-based application within the California Avian Data Center [CADC] that provides access to our findings and visualization tools which summarize our avian demographic data. Results can be visualized by natural resource managers at our project website: ***http://data.prbo.org/apps/aviandemog***

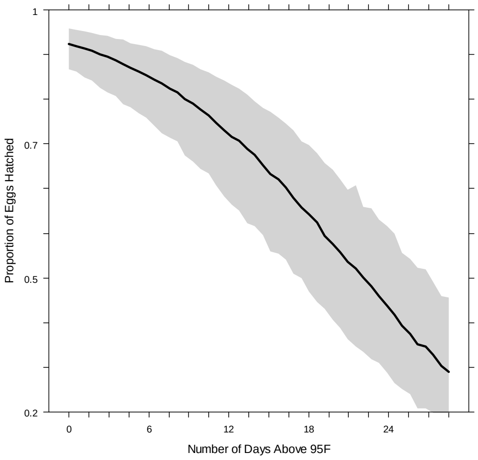
Waterfowl Nesting in the Central Valley and San Francisco Bay-Delta

- We used two long-term datasets on nesting dabbling ducks in the 1) Suisun Marsh at the Grizzly Island Wildlife Area that spans from 1985 to 2010 (23 years total) and contains 13,803 nest histories and 2) Central Valley at Conaway Ranch that spans from 1991 to 2006 (13 years total) and contains 1,229 nest histories.
- Nest survival declined with mean daily temperature for Mallard and Gadwall at both sites. Rainfall was not consistently correlated with nest survival among species or sites.
- Egg hatching success declined strongly with extreme temperatures (number of days eggs were incubated when temperature was ≥95°F) for Mallard at both sites and Gadwall in Suisun Marsh.
- Gadwall clutch sizes declined with increasing mean daily temperatures in late spring. This decline was much more pronounced in the Central Valley then in the Suisun Marsh where temperatures were more moderate due to the proximity to the bay.
- For both Mallard and Gadwall, nesting season length increased with amount of rain during the pre-breeding season in Suisun Marsh, however nesting season length was not influenced by rainfall in any

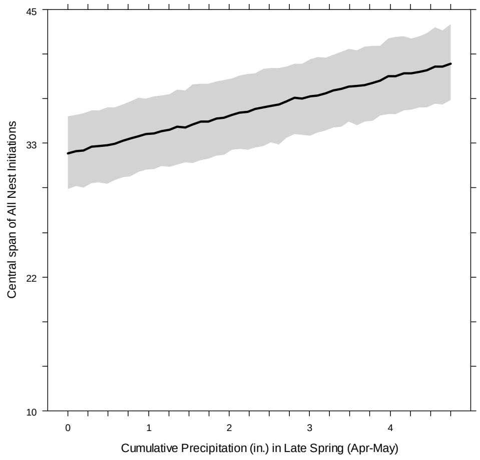
Conaway Ranch--Mallard



Grizzly Island--Mallard



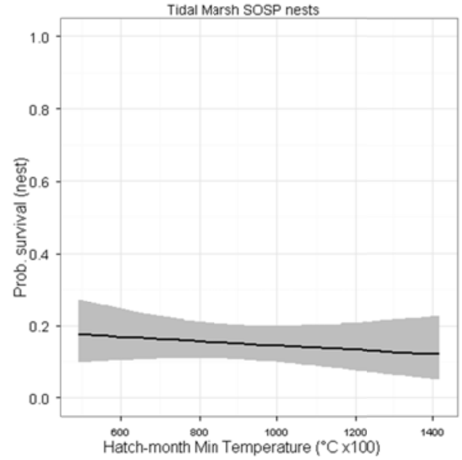
Grizzly Island--Mallard

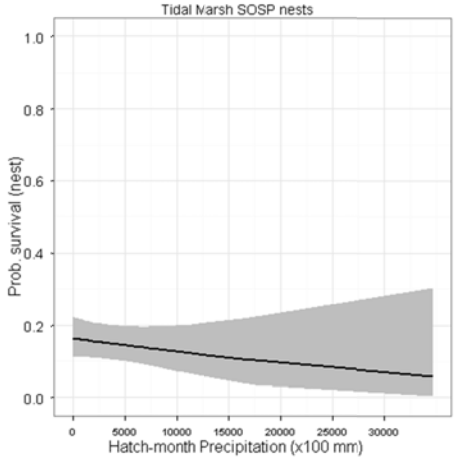


season in the Central Valley.

- In Suisun Marsh, Mallard, and to a lesser extent Gadwall, initiated nests later when there was more rain in late winter, and nesting season length (central span) increased with late spring rain.
- Mallard initiated nests earlier when spring temperatures were warmer in Suisun Marsh.
- Gadwall nesting season length decreased with early spring temperatures in Suisun Marsh, but nesting season length increased with early spring temperatures in the Central Valley due to earlier nesting.

<u>Songbird Nesting at Point Reyes National Sea Shore and North San Francisco Bay</u>

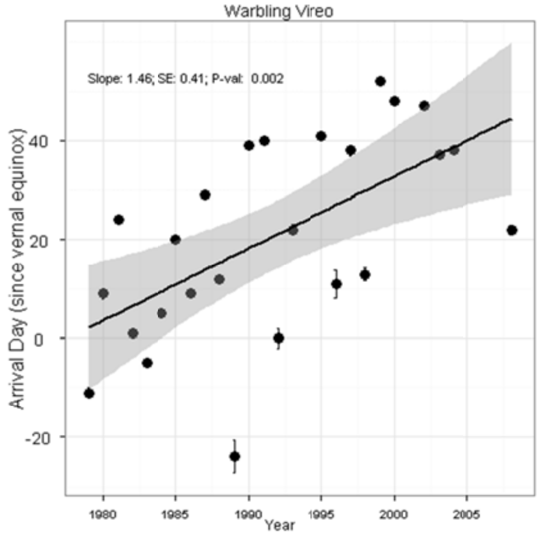




- We used several long-term datasets on nesting songbirds in the 1) Point Reyes National Sea Shore at the Palomarin Research Station that spans from 1996 to 2008 (13 years total) and contains 1,049 nest histories and 2) tidal marshes within sites along the North San Francisco Bay that spans from 1996 to 2006 (11 years total) and contains 3,020 nest histories.
- Wrentit nest survival increased with hatch-month minimum temperature at Palomarin, but nest survival in Song Sparrows decreased with hatch-month minimum temperature, especially in tidal marshes where temperatures varied more widely than at Palomarin. Songbird nest survival was not related to any other temperature metric assessed.
- Nest survival was (slightly) positively related to

hatch-month precipitation for Wrentit at Palomarin, but nest survival was negatively related to hatch-month precipitation for tidal marsh Song Sparrows.

Songbird Arrival Dates at Point Reyes National Sea Shore

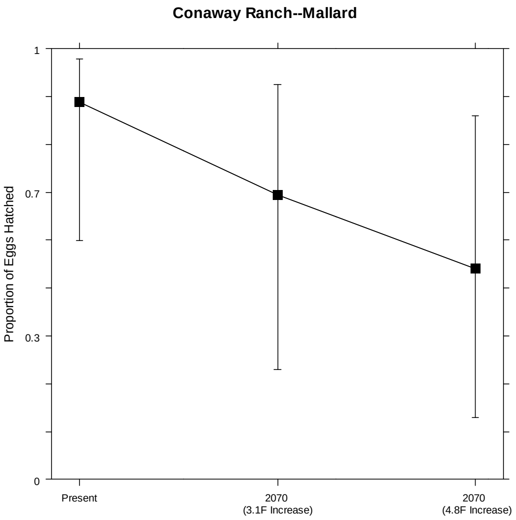


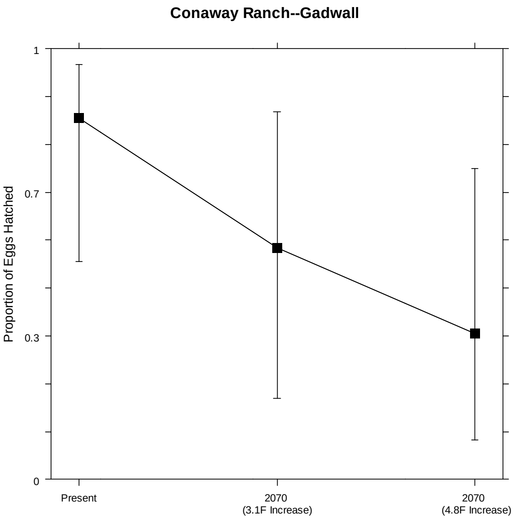
- Date of first arrival has not significantly changed over time for songbirds, except for Warbling Vireo. However, Warbling Vireo has decreased in abundance at Palomarin, so the observed trend may be due to declining numbers.
- Day of first arrival for songbirds was related to large-scale climate index variables for only three Neotropical migrants. Barn Swallow arrival date declined with the cumulative monthly value of the Northern Oscillation Index, indicating later arrival dates during El Niño years. Black-headed Grosbeak arrival date declined with ENSO values, indicating earlier arrival dates during El Niño events. Pacific-slope Flycatcher arrival dates declined with the Pacific Decadal Oscillation and increased with the Southern Oscillation Index, suggesting later arrival dates during warmer years.

Climate Change Projections – Waterfowl

- By 2070, climate models project overall mean temperatures in the Central Valley to increase from 3.1^{o} – 4.3^{o}F, with increased frequency of heat waves, and precipitation is expected to decrease by 1.9 – 6.9 inches.
- Egg hatching success is projected to decline for both Mallard and Gadwall at both sites.

This expected decline in hatching success is especially pronounced for ducks nesting in the Central Valley where temperatures can become extremely high without the cooling and stabilizing properties of the bay and coastal regions.

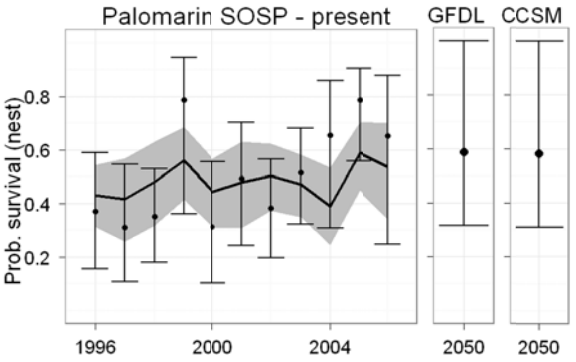


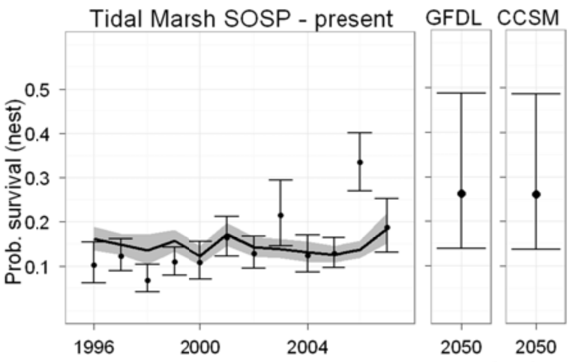


- Clutch sizes are projected to decrease by approximately 6% for Mallard and 10% for Gadwall in Suisun Marsh, but less so for ducks nesting in the Central Valley.
- Nesting season length is projected to change most dramatically for ducks nesting in the Central Valley. Mallard nesting season length is expected to shorten considerably, due mainly to the season ending earlier than it currently does, whereas the Gadwall nesting season, who initiate nests later in the season, is expected to increase, due to earlier nesting.

__Climate Change Projections – Songbirds__

- Future projections for the Song Sparrow and Wrentit suggest slightly enhanced nest survival.





Management Implications

- Our results suggest that, in California, waterfowl demographics appear to be strongly related to climate variables whereas songbird demographics are not. This could be due in part to differences in habitat type among species, as many of the strongest relationships with temperature occurred for ducks nesting in the Central Valley where temperatures can be extremely hot without the moderating influence of the bay and coastal regions.
- Projections suggest that increased temperatures will have the strongest negative effects on waterfowl egg hatching success. Management for dense nesting cover and vegetation that provides shading for eggs later in the nesting season could improve hatching success.
- Future precipitation estimates are uncertain, but water will undoubtedly become an increasingly scarce commodity for wildlife as use by agriculture and urban development likely will increase in the future. Management actions to ensure waterfowl have access to wetlands that are adjacent to nesting habitat will be essential.
- Arrival dates for songbirds may differ in the future, with some species like Barn Swallows arriving later and other species like Black-headed Grosbeaks arriving earlier. This potentially sets the stage for mismatches between resources and nesting phenology.

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Introduction

The presence and persistence of a species on the landscape is determined by the complex effects of biophysical variables on demographic parameters of populations of the species, such as survival and productivity. Understanding the biophysical effects on avian demographics provides a sound foundation for natural resource management, including more robust predictions of future species distributions and species population viability. Management actions can then be directly linked to demographic changes (Van Turnhout et al. 2010), such as changes in nest survival.

Studies assessing how animal demographics have responded to climate variables can provide insight on the drivers of population changes and for more robust predictions of future species distributions and population viability (Both et al. 2006, Robinson et al. 2007, Wright et al. 2009). In particular, knowing the conditions that are most favorable for bird nesting and nest survival allows managers to more accurately identify, outline, restore, and manage landscapes and regions for increased productivity (Seavy et al. 2008). Metrics of productivity and survival also are necessary to properly estimate population trends. These are the building blocks of population viability analyses. Determining the drivers of population changes allows for proper modeling of future population scenarios.

Herein, we evaluate how avian demographic parameters are likely to respond to climate change for a suite of species and provide a web-based tool to assist natural resource managers with understanding the potential future impacts of climate change and the specific effects of environmental variables. We used two main guilds of birds, waterfowl and songbirds, and a gradient of habitats from the Coast Range, through the San Francisco Bay, and into the Central Valley of California.

Objectives

Specifically, we:

1) Assessed and synthesized several breeding demographic responses to climate change variables (i.e., precipitation and temperature).
2) Created a web-based application (within the California Avian Data Center [CADC]; ***http://data.prbo.org/apps/aviandemog/***) that provides access to our findings and supports the visualization and summarization of avian demographic data.

Background

We used the two largest datasets on breeding waterfowl in California (1985 – 2010) to compare how the breeding demographic parameters of Mallard (*Anas platyrhynchos*) and Gadwall *(Anas strepera*) differ with temperature and precipitation patterns between the two major breeding habitats within the Central Valley and Suisun Marsh. We used long-term (1996-2008) nest monitoring datasets collected and maintained by PRBO Conservation Science for bird species breeding at the Palomarin Field Station in the Point Reyes National Sea Shore (hereafter Palomarin), and locations in the tidal marsh along the north San Francisco Bay. Lastly, we used one of the largest datasets in the country of constant-effort banding data, from Palomarin, to determine the date of first arrival of Neotropical and Nearctic migrant bird species, and its relationship with four large-scale climate indices.

Study Sites

Waterfowl data were collected at two locations: Conaway Ranch (38.6472 N, -121.6683 E) and Grizzly Island Wildlife Area (38.1552 N, -121.9757 E). Conaway Ranch is located in the Central Valley of California, just east of the towns of Woodland and Davis. Grizzly Island Wildlife Area is located within the Suisun Marsh in the transition zone between the San Francisco Bay and the Sacramento-San Joaquin River Delta. Temperatures within the Central Valley can become extremely hot during the summer, whereas Suisun Marsh temperatures are more moderate as they are buffered by the large expanses of water within the San Francisco Bay and proximity to the coast.

Songbird data were collected at two general study sites – the Palomarin Field Station, located within the Point Reyes National Sea Shore, 20 Km north of the city of San Francisco, California, and the San Francisco Bay northern tidal marshes (hereafter the “tidal marshes”) for Song Sparrows [*Melospiza melodia*] only. The weather and vegetation at Palomarin has been extensively documented elsewhere (e.g., Silkey et al. 1999, Chase et al. 2005). The site is primarily a mixture of dense mature coastal scrub with encroaching Douglas fir (*Pseudotsuga menziesii*), and an oak-bay riparian area. The tidal marsh study site encompasses five specific locations: China Camp (southwestern San Pablo Bay; -122.4956 E, 38.0123 N), Black John Slew/Carl’s Marsh/Petaluma River Restoration Marsh/Petaluma River Mouth (-122.5057 E, 38.1241 N), Pond 2A Restoration Marsh (on the Napa river east of San Pablo Bay; -122.32133 E, 38.153 N), Southampton/Benicia Marsh (-122.1934 E, 38.0736 N), and Rush Ranch (north Suisun Bay; -122.0268 E, 38.2022 N). All marshes are restoration sites at ≥10 years of age. Dominant plant species include pacific cordgrass (*Spartina foliosa*) annual and perennial pickleweed (*Sarcocornia* spp.), bulrushes (*Bolboschoenus* spp. and *Schoenoplectus* spp.), cattails (*Typha* spp.), and shrubs, such as coyote bush (*Baccharis pilularis*).

Species Descriptions

Mallard (*Anas platyrhynchos*) and Gadwall (*Anas strepera*) are both waterfowl within the Anatinae sub-family, also called “dabbling ducks”. These species differ in their life history strategies, with Gadwall having a “faster” life history strategy than Mallard, characterized by having a higher reproductive output and shorter lifespans than Mallard (Ackerman et al. 2006). Population estimates for Mallard in California is higher than for Gadwall, and while both species are found year round within the Central Valley and Suisun Marsh, the number of Mallard breeding in these areas are about 3 times higher than the number of breeding Gadwall. Mallard are larger birds, but their reproductive output (i.e., clutch mass / body mass) is smaller than Gadwall (Ackerman et al. 2006). Mallard lay an average of 9 eggs and incubate their clutch for approximately 26 days, whereas Gadwall lay 11 eggs and incubate their clutch for approximately 24 days (Klett et al. 1986). Both species nest on the ground in upland vegetation near wetlands, and, at hatch, females lead precocial ducklings to water.

Song Sparrows are territorial passerines found in many kinds of open habitats throughout North America and northern Mexico (Arcese et al. 2002), but particularly in riparian habitats and marshes. The Marin subspecies, *M. m. gouldii,* found at Palomarin, the Suisun subspecies, *M. m. maxillaris*, found in the tidal marshes around Suisun Bay, and the Samuel’s subspecies, *M. m. samuelis*, found in San Pablo Bay, are all local breeders and year-round residents (Humple and Geupel 2004). Although primarily monogamous, males may mate with multiple females. Clutch size is 2-5 eggs, with incubation period lasting approximately 13 days and nestling period about 9 days (Jongsomjit et al. 2007). At Palomarin a 3-egg nest fledges chicks in 24 days, whereas at the tidal marshes chicks fledges in 23 days. Wrentits (*Chamaea fasciata*) are also year-round territorial passerines, though more strictly monogamous than Song Sparrows (Geupel and Ballard 2002). The species is confined to the coastal scrub and chaparral habitats of Pacific North America. The most notable characteristic of the Wrentit, in contrast to the Song Sparrow, is that the male helps in incubation, and both incubation and fledging periods are longer. A 3-egg clutch (clutches vary from 1 to 5 eggs) takes approximately 32 days to fledge chicks at Palomarin (Geupel and Ballard 2002, Jongsomjit et al. 2007).

The species selected for the analysis of Date of First Arrival were chosen for their documented sensitivity to climate and weather (MacMynowski et al. 2007; PRBO unpublished data) and high capture rates. These include the following Neotropical migrants: Barn Swallow (*Hirundo* *rustica*), Black-headed Grosbeak (*Pheucticus melanocephalus*), Cliff Swallow (*Petrochelidon pyrrhonota*), MacGillivray's Warbler (*Oporornis tolmiei*), Northern Rough-winged Swallow (*Stelgidopteryx serripennis*), Olive-sided Flycatcher (*Contopus cooperi*), Orange-crowned Warbler (*Vermivora celata*), Pacific-slope Flycatcher (*Empidonax dificilis*), Swainson's Thrush (*Catharus ustulatus*), Warbling vireo (*Vireo gilvus*), Wilson's Warbler (*Dendroica pusilla*), and Yellow Warbler (*Dendroica petechia*). Three species of Nearctic migrants were selected for the analysis as well: Fox Sparrow (*Passerella iliaca*), Golden-crowned Sparrow (*Zonotrichia atricapilla*) and Ruby-crowned Kinglet (*Regulus calendula*).

Nest Monitoring Data and Methods

The Grizzly Island Wildlife Area dataset represents 23 years of breeding waterfowl data, and nearly 14,000 nests. Data have been collected at this site for every year since 1985, except for 2005-2007 when funding was not available (**Table 1**). Conaway Ranch was monitored in 1991, and 1995-2006 (**Table 1**), representing 13 years and over 1,000 nests. For detailed descriptions of the field methods used to collect waterfowl data see McLandress et al. (1996), Ackerman (2002), and Ackerman et al. (2003a,b,c, 2004). Nest searches were initiated each year in early April and continued until July to ensure finding both early- and late-nesting ducks. The date of nest initiation was calculated by subtracting the age of the nest when found (i.e., the number of eggs when found plus the incubation stage when found) from the date the nest was discovered. Each field was searched four to five times at 3-week intervals until no new nests were found. Nest searches began at least 2 hours after sunrise and were finished by 1400 hours to avoid missing nests due to morning and afternoon incubation recesses by females. Nest searches were conducted using a 50-m nylon rope strung between two slow-moving all-terrain vehicles. Tin cans containing stones to generate noise will be attached at 1.5-m intervals along the length of the rope. The rope was dragged through the vegetation, causing females to flush from their nests, thus enabling observers to locate nests by searching a restricted area. Nests were marked with a 2-m bamboo stake placed 4 m north of the nest bowl and a shorter stake placed just south of the nest bowl, level with the vegetation height. Each nest was revisited on foot once every seven days, the stage of embryo development was determined by candling, and clutch size and nest fate were recorded. After each visit, we covered the eggs with nest materials (i.e., down and contour feathers from the nest), as the female would have done before leaving for an incubation recess.

Table 1. *Total number of nests monitored at Grizzly Island Wildlife Area, Conaway Ranch, Palomarin Research Station, and North Bay tidal marsh locations.*

Study Site	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Grizzly Island	508	590	632	667	564	376	621	765	491	1107	1005	1181	819
Conaway Ranch	-	-	-	-	-	-	64	-	-	-	146	183	85
Palomarin	-	-	-	-	-	-	-	-	-	-	-	123	89
Tidal Marshes	-	-	-	-	-	-	-	-	-	-	-	154	346

Study Site	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
Grizzly Island	656	483	537	425	284	384	169	-	-	-	333	304	902	13803
Conaway Ranch	123	70	60	48	55	51	83	179	82	-	-	-	-	1229
Palomarin	130	47	72	62	104	125	79	93	46	66	13	-	-	1049
Tidal Marshes	172	346	181	310	344	128	247	441	351	-	-	-	-	3020

Nest searching and monitoring at Palomarin began in 1980 and is ongoing; the dataset used here includes years 1996 to 2008. All nests were located at various stages (from building to nestling periods) and were monitored using a standard protocol designed to minimize human disturbance (Martin and Geupel 1993). The number of days between visits varied (1-14 days, mode = 3 days), though effort was made to visit every 2-4 days to increase accuracy in estimates of date of predation or abandonment, and egg laying. We reviewed the records and discarded any data pertaining to building stages, or records of nests whose clutch date was unknown or could not be estimated, resulting in a dataset with 437 nests of Song Sparrow and 612 nests of Wrentit monitored between 1996 and 2008; totaling 3,778 records of nest checks (**Table 1**). Nest search and monitoring at the tidal marsh sites followed the same abovementioned methodology. Search and monitoring of nests at the tidal marsh locations began in 1996 and continued through 2007. Not all five locations contain nest records for all years, since not all were surveyed throughout the period. The tidal marsh dataset includes records for 3,020 Song Sparrow nests, totaling 12,315 nest check records (**Table 1**).

The banding methods used at Palomarin follow the general methodology outlined in Ralph et al. (1993). Full details can be found in the California Avian Data Center (http://data.prbo.org/cadc2/index.php?page=songbird-tools) and in Gardali et al. (2000). The banding station has been running year-round since 1965, with standardized sampling effort since 1979. For this reason, we include only data for captures between 1979 and 2009. A total of 20 nests are monitored 6-7 days each week for 6 hours. We used only data for each species and year spanning the date of first capture and the subsequent 20 banding days, including records from new captures of adult individuals only (i.e., after-hatch year or older).

Avian Breeding Demographic Parameters

Climate has the potential to not only influence when birds initiate nests, but how long they can keep nesting, or how many nests can be initiated. Climate variables also can extend beyond phenology, by directly influencing the nest survival, or the hatching success of individual eggs. Thus, to fully assess the impacts that climate, seasonal, and daily weather conditions can have on breeding waterfowl in California, we modeled a large suite of breeding parameters that represent all periods and facets of the nesting season (**Table 2**). For songbirds, we focused only on nest survival.

For the waterfowl data analyses, breeding parameters were estimated at either the individual level or the site level, depending on what was most appropriate. Nest survival, clutch size, hatching success (i.e., proportion of eggs that hatched in a successful nest), and the initiation date of a nest were all summarized at the individual nest level. Breeding season length was estimated at the site level.

Below, we provide methods for estimating each breeding parameter, as well as some of our thinking as we developed suites of *a priori* hypotheses related to how weather and climate might affect each of these demographic parameters.

Clutch Size

Method of estimation - Clutch size was defined as the total number of eggs laid in the nest. Only nests that were found within 8 days of laying and showed no signs of partial depredation (Ackerman et al. 2003a) were included in our analyses.

Candidate set of covariates – It is assumed that ducks obtain most of the resources required for egg formation on the breeding grounds. Thus, any weather variables that may influence what resources will be available in the breeding area in the 2-3 weeks prior to a nest being initiated were included. Since nests were initiated until late June/early July, we selected variables that could influence invertebrate production, and included mean and minimum temperatures in all monthly groupings (see **Table 3**) as well as cumulative precipitation. It is also well documented in the literature that clutch size in ducks declines throughout the breeding season. Thus we added the date of nest initiation as an additional covariate. We did not include any 2-way interactions and restricted any single model to a maximum of 8 parameters.

Table 2. *Breeding demographic parameters estimated from the data.*

Response variable	**Species**	**Definition**
Clutch size	Waterfowl	Clutch size by nest
Nest initiation date	Waterfowl	Nest initiation date by nest
Proportion of eggs hatched	Waterfowl	Proportion of eggs within a clutch that hatched from a successful nest
Central span of nesting season	Waterfowl	Central span of nesting season length (number of days between when 10% and 90% of all nests were initiated)
10th percentile nest initiation date	Waterfowl	Date when 10% of all nests were initiated
90th percentile nest initiation date	Waterfowl	Date when 90% of all nests were initiated
Daily nest survival probability	Songbirds & waterfowl	Probability of daily nest survival of a nest
Probability of nest survival	Songbirds	Probability of nest surviving from clutch completion to fledging date
Date of first arrival	Songbirds	Date the species was first detected at Palomarin

Table 3. *Delineations of seasons used to summarize weather covariates.*

Season	Months
late.winter	December - January
early.spring	February - March
late.spring	April - May
early.summer	June - July

Nest Initiation Date, Central Span of Nesting Season, and 10th and 90th Percentile of Nests Initiated

Method of estimation – Nest initiation date was defined as the date at which an individual female laid the first egg in the nest. Only nests where researchers were confident that nest initiation date could be estimated were included. Nest initiation date was estimated by subtracting the initial clutch size plus the average incubation stage of all eggs in the clutch on the day the nest was first discovered from the date the nest was found. In addition to the estimation of each nest's individual initiation date, estimates of the dates when 10% and 90% of nests were initiated for each site (nesting field) within each region. In addition, the central span of nests, or number of days between the dates when 10% and 90% of all nests within a site were initiated, was estimated as a metric for the duration of the nesting season.

Candidate set of covariates – We selected variables we believed would influence the availability and timing of suitable nesting habitat for ducks. In general, ducks prefer to nest in dense cover within larger fields that are within a reasonable distance to water to support ducklings after hatch. Thus, variables that would affect the condition of habitats within nesting fields (e.g., precipitation and temperature in winter and spring) were selected (**Appendix 2**). The end of nest initiations during a season is a combination of available resources and life history constraints. Warmer conditions and changed habitats later in summer may reduce the availability of the specific resources necessary for egg formation. Thus, we hypothesized that the termination of nesting would be influenced by conditions in late spring and early summer primarily, though we deemed it possible that early spring weather may build the foundation for how long resources were available.

Proportion of Eggs Hatched (Hatching Success)

Method of estimation – Hatching success is defined as the proportion of eggs that hatched within a nest that was successful (i.e., where at least 1 egg hatched). Thus, only successful nests where full clutch size and final fate for each individual egg was known were included in our analyses (after Ackerman et al. 2003a).

Candidate set of covariates – We hypothesized that extremely hot temperatures for longer periods of time may exceed an incubating female's ability to protect the eggs from over-heating. Whereas it is possible that thermal stress may also influence overall nest survival (see below), thermal stress may also only influence a fraction of eggs depending on their location in the nest bowl. Variables we selected *a priori* represented either immediate or direct effects of temperature for that nest (e.g., number of days during the incubation period where temperatures exceeded 95°F), as well as overall general seasonal temperature measures (**Appendices 2 & 4**).

Nest Success - Waterfowl

Method of estimation – Nest success for each site was estimated as the product of modeled daily survival rate estimates for each day of an average nest. A nest starts on the day the first egg is laid in the nest, and continues through the period of egg laying (9 days for Mallard and 11 days for Gadwall) and incubation (26 days for Mallard and 24 days for Gadwall). Thus, each Mallard and Gadwall nest must successfully survive 35 days to be successful. Nest survival was estimated separately for each region and species using the `nestsurvival (`Herzog 2011) package in R, and was based on the logistic exposure model (Shaffer 2004). A successful nest was defined as a nest where at least 1 egg hatched. For some nests, it was possible to determine the exact date of the nest's fate. However, in most cases, the final nest fate date was estimated in the same manner as is done for Mayfield nest success; that is, the date that represents the midpoint of the final visit interval when the nest fate was determined (Mayfield 1961, Mayfield 1975, Johnson 1979). Only nests where at least 1 day of exposure occurred were included in analyses.

Candidate set of covariates – Model selection was performed in a two-step process. First, we developed a base model, by assessing all possible models associated with date, nest age, age of nest when found, relative nest initiation date (relative to other nests in the given year and region), and year, including squared terms for most variables (see **Appendices 2 & 4**). For all regions and species, the data strongly supported 2 models. Both models were identical (single linear combinations of all variables), differing only by the inclusion (or exclusion) of "age when found". Since the favored model among the analyses was not consistent and never > 2 AIC_c different, and because of our belief that survival might be inherently different for nests found when they are older, we included the variable "age when found" in our base model.

Nest Success - Songbirds

Method of estimation - We constructed 73 different competing generalized linear models with a logistic-exposure model (i.e., a logistic link constructed as described by Shaffer 2004) using the R package `nestsurvival` (Herzog 2011) using a very similar approach to that described within the waterfowl section. We evaluated combinations of the climatic variables that would account for the three biophysical parameters described below. Additionally, we accounted for the possibility that the daily survival rate could vary throughout the life of the nest by including a linear, quadratic, or cubic parameter for the age of the nest. Similarly, the daily survival rate also may vary depending on the date of the nest with respect of the beginning of the nesting season, so that nest attempts at the beginning and end of the season may be less successful than those in the middle. We accounted for this effect by adding linear, quadratic, or cubic parameters for the date of the nest with respect to the beginning of the season (the first clutch date for each year). Lastly, we considered the possibility of unaccounted for variance between years by modeling year as a discrete explanatory variable.

The response parameter of the models, survival of the nest to the exposure interval (the interval between nest checks), was scored by determining whether the nest was still active or had successfully fledged at least one young, or was depredated/abandoned at the end of the interval. We thus assigned 1's or 0's respectively to each check. We omitted first observation records unless these coincided with the clutch date (i.e., left censoring of records to avoid artificially inflating the survival estimates by considering only nests known to have survived until they were discovered). We assigned an age of the nest as the middle day of the interval between checks, and a date of the nest in the season as the date of the middle of the interval with respect to the first clutch date for the appropriate year.

Variable importance was evaluated directly from each model fit in the set of competing models by simply counting the number of models in which the variable contributed significantly (p-value <0.05) to the fit.

Predicting to the future climate scenarios was done by attributing all current records with the future temperature and precipitation values under either one of the two models we considered. We then averaged the value of each climatic variable in the data and used these average values to predict with the set of competing models. Thus the resulting predicted future survival probabilities reflect variance across locations and model uncertainty.

Candidate set of covariates for songbirds - We first calculated 13 derivative environmental variables from the PRISM variables and the future climate datasets, listed in **Appendix 2**. Each one of these is intended to be a proxy measurement of three potentially important biophysical parameters potentially affecting the survival probability of Song Sparrows and Wrentits. The first parameter known to affect Song Sparrow nest survival is precipitation in the prior rainy season (Chase et al. 2005). How much vegetation growth and insect productivity may occur at the sites is likely largely dependent on the amount of precipitation in the rainy season (between October and March, hereafter bioyear precipitation). Chase (2002) speculate that the amount of bioyear precipitation is directly associated with the amount of foliage that provides for nest cover. On low precipitation years nest cover is poor and predation is high, and vice versa. We also considered precipitation one to three months prior to the hatch month as proxy measures of vegetation growth and productivity. Competing models had one of these variables. The second parameter potentially affecting nest survival is minimum and maximum temperature one to three months prior to the hatch month (Chase et al. 2005). Lastly, DeSante and Geupel (1987) observed a large proportion of nests abandoned during a nesting period of particularly high rainfall. Chase et al. (2005) also investigated the effect of temperatures to nest survival. Thus, we evaluated the effect of total precipitation and minimum and maximum temperature during the hatch month.

Date of First Arrival

Method of estimation - For each year and each species, day of first arrival was estimated as the intercept parameter of the regression of date against the cumulative capture rate in the banding data; that is, the point when the cumulative capture rate is 0 just before the first capture is made. The date was converted to days since vernal equinox to reduce bias that changes in timing of actual spring can have on calendar dates (Sagarin 2001).

Candidate set of covariates - Since climatic conditions affecting arrival dates may not be those of the winter or summer grounds (for Neotropical or Nearctic migrants, respectively), we explored parameters derived from four large scale climate indices to correlate to the arrival date estimates. Species abundance patterns and fecundity also correlate with patterns of date of first arrival (Miller-Rushing et al. 2008) and are affected by many other parameters not considered here (Gordo 2007).

Climatic Covariates and Analysis Methods

Weather Data – Waterfowl Analyses

Weather covariates (see **Appendix 1**) used in waterfowl data analyses were summarized from daily weather station data collected at weather stations near each study area and downloaded from the National Climate Data Center (NCDC; http://www.ncdc.noaa.gov). Units are presented as received from NCDC as degrees Fahrenheit (°F) for temperature, and inches for cumulative precipitation.

Given the unique location of Grizzly Island Wildlife Area, and lack of weather data in the immediate vicinity, we were concerned that weather data would not adequately represent the region. Weather data, however, had been collected at Grizzly Island Wildlife Area in early years (1971-1977). Therefore, we retrieved daily weather data from several stations within the area (cities of Antioch, Fairfield, Martinez, and Vacaville) as well as Grizzly Island Wildlife Area for the period 1970-1979. Using the `hclust` procedure (Venables and Ripley 2002) in R, we performed agglomerative hierarchical clustering (Gordon 1999) to understand which sites were most similar to each other with respect to precipitation (total daily accumulation) and temperature data (minimum, mean, and maximum daily temperature). These results suggested that weather in Antioch and Fairfield were much more similar to Grizzly Island Wildlife Area weather than either Martinez or Vacaville. We then performed simple regressions with Grizzly Island Wildlife Area weather data as the response variable and Antioch and Fairfield weather as covariates to understand how the information from each of these stations contributed to the Grizzly Island Wildlife Area weather station data. Results indicated that temperature could be represented approximately as the weighted average of 0.6*Fairfield temperature and

0.4*Antioch temperature (R^2 = 0.98). For precipitation, Grizzly Island Wildlife Area rainfall was approximated by the weighted average of 0.4*Fairfield precipitation and 0.6*Antioch precipitation (R^2 = 0.65). Given the difference between temperature and weather relationships and since this comparison was made on a small amount of data many years prior to our actual study, we opted to simply take the mean of the Antioch and Fairfield daily weather station data to represent all Grizzly Island Wildlife Area weather during our study. Validating this relationship, showed that it had little effect on the relationship (temperature R^2 = 0.96; precipitation R^2 = 0.61).

Conaway Ranch weather data was much more straightforward. Situated equidistant from both Davis and Woodland weather stations, we took the combined mean daily weather data from the cities of Davis and Woodland to represent the weather at Conaway Ranch.

For both Grizzly Island Wildlife Area and Conaway Ranch, when daily weather data were not available for 1 weather station, only weather data from the second weather station was used.

Weather Data – Songbird Analyses

Climate data for the Song Sparrow and Wrentit data analyses were downloaded from the PRISM project (PRISM 2011), thus including monthly minimum and maximum temperatures and monthly total precipitation. The PRISM datasets are grids of 4 x 4 km, so the entire Palomarin dataset was included within a single cell of the PRISM grid. All six locations from the tidal marsh dataset are in different cells of the PRISM dataset. Since the climate data are extrapolated from nearby weather stations based on geomorphological attributes, the tidal marsh locations showed little difference in climate parameter values.

Future scenario data for the songbirds were obtained for a single average year (averaged for the 30 years between 2040 and 2070) based on projections from a regional climate model, RegCM3, with emission trajectory taken from the Intergovernmental Panel on Climate Change A2 scenario and boundary conditions based on output from two global circulation models. A full description of the future dataset is provided by Stralberg et al. (2009).

We used the following four large scale climate indices: El Niño Southern Oscillation Index (ENSO – http://www.coaps.fsu.edu/jma.shtml), Pacific Decadal Oscillation Index (PDO – http://jisao.washington.edu/pdo/PDO.latest), Southern Oscillation Index (SOI), and Northern Oscillation Index (NOI) (both found at:

http://www.pfeg.noaa.gov/products/PFEL/modeled/indices/NOIx/noix_download.html). These links provide full description of the indices. We evaluated three parameters derived from these indices that we expected may influence date of first arrival for each species: sum of monthly index values from October to December of the previous year, sum of index values from January to March of the arrival year, and sum of index values from October to March.

All analyses were performed in the statistical programming language R (version 2.13.0; R Core Development Team 2011).

Statistical Methods

Waterfowl

We used a consistent approach for modeling all breeding parameters. For waterfowl, analyses were performed for each combination of species (Mallard and Gadwall) and region (Grizzly Island Wildlife Area and Conaway Ranch) separately. Thus, a total of four analyses were completed on each of the breeding variables. We used a linear mixed model approach (Pinheiro and Bates 2000) with year and site (nesting fields within each region) as random effects. For each breeding parameter, we developed a set of plausible candidate models from the available suite of weather covariates (see **Appendices 2 & 4**).

The candidate model set consisted of all possible linear combinations of the weather covariates selected. The result was a very large set of possible models and a complete candidate model set consisting of between 31-255 models, depending on the breeding parameter. All candidate models were run and model inference diagnostics were calculated for each model (Burnham and Anderson 2002). For predictions and figures, we model-averaged the suite of best models that contributed 99% of the total model weight (as calculated by the AIC_C weights for each model within the given model set). Model averaged predictions were derived from 1000 simulations of each model within the model set (Gelman and Hill 2007). Predictions and 95% credible intervals are presented as the mean, 5th percentile, and 95th percentile from these simulations (Gelman et al. 2003).

Songbirds

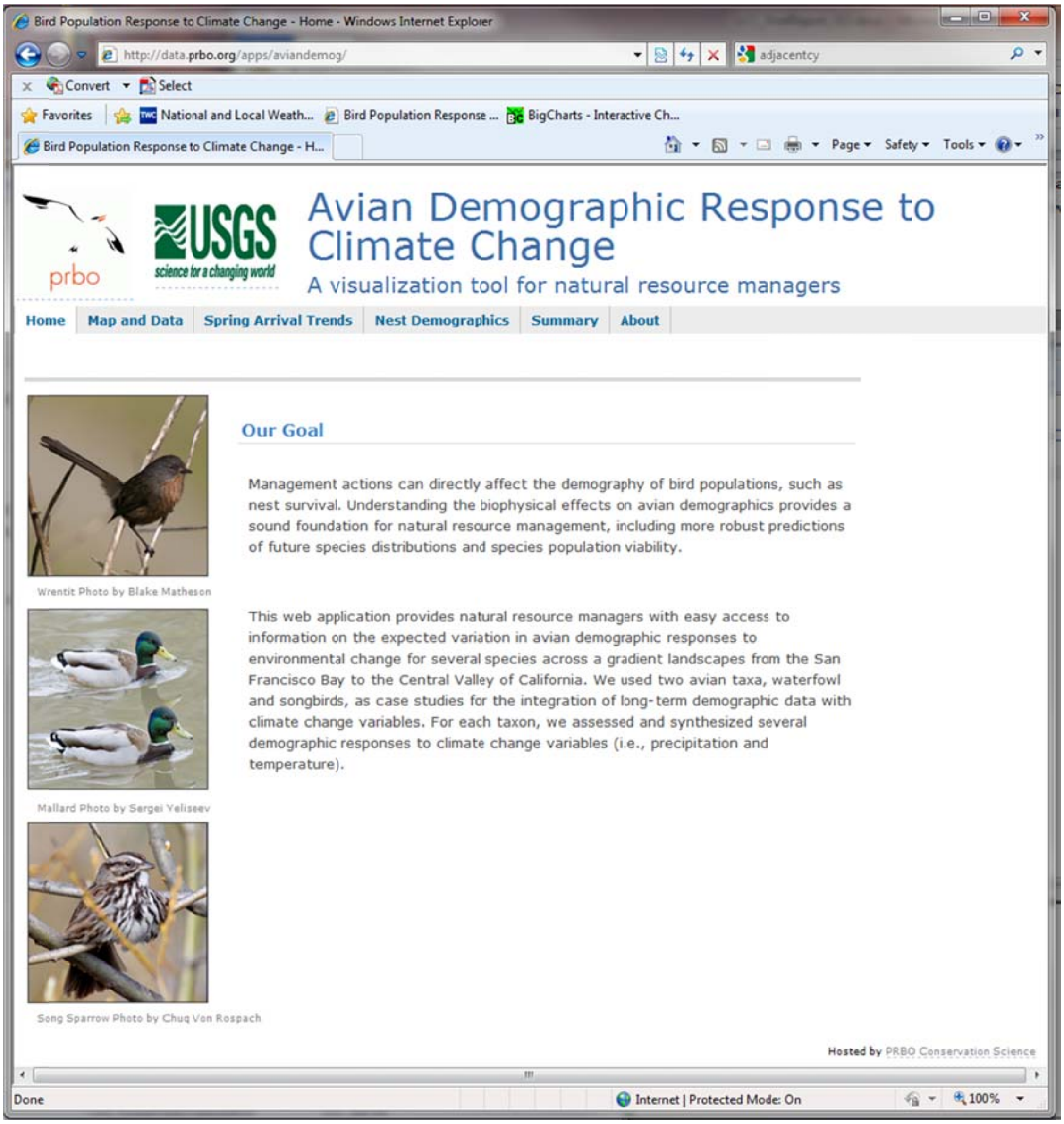
To estimate nest survival probabilities for songbirds, we fit models to each species and location separately, thus resulting in three analyses for daily and nesting survival. The models for the songbirds considered the possibility of unaccounted variance between years by modeling year as a discrete explanatory variable. We considered only the set of models within 2 AIC units of the top model as the competing model set (Burnham and Anderson 2002). This resulted in 10-14 competing models to estimate the nest survival probabilities for each species and location. As with waterfowl analyses, for each breeding parameter we developed a set of plausible candidate models from the available suite of weather covariates (see **Appendix 1**). The nest survival estimates by year were then obtained by averaging the predicted survival values from each model, weighted by the goodness of each model fit (AIC weights).

For the analysis of day of first arrival patterns, we sought to detect the significant contribution of any of the three parameters derived from the large-scale climate indices. We did not pursue construction of predictive models. We restrict our discussion to how these parameters affect arrival to speculate how future higher frequency of particular index values (i.e., global climatic conditions) may affect arrival.

Results and Discussion

We created a web-based application within the California Avian Data Center [CADC] that provides access to our findings and visualization tools which summarize our avian demographic data. Results can be visualized by natural resource managers at our project website:

http://data.prbo.org/apps/aviandemog



Our Goal

Management actions can directly affect the demography of bird populations, such as nest survival. Understanding the biophysical effects on avian demographics provides a sound foundation for natural resource management, including more robust predictions of future species distributions and species population viability.

This web application provides natural resource managers with easy access to information on the expected variation in avian demographic responses to environmental change for several species across a gradient landscapes from the San Francisco Bay to the Central Valley of California. We used two avian taxa, waterfowl and songbirds, as case studies for the integration of long-term demographic data with climate change variables. For each taxon, we assessed and synthesized several demographic responses to climate change variables (i.e., precipitation and temperature).

Waterfowl Results

Clutch size

For all species and sites, clutch size declined with nest initiation date (β = -0.05 to -0.03 eggs/day), and represented a reduction of 1-2 eggs throughout the entire breeding season (mean breeding season length was 43 days; **Figure 1**). At all sites, weather covariates representing temperatures during early and late spring were in the top models based on AIC_c (**Figure 2**). Gadwall clutch size consistently declined with temperature in late spring (April – May). Although present in the top models, Mallard clutch size did not show a consistent pattern with temperature between study sites, nor did the slope estimates of the relationship deviate significantly from zero.

The strong negative effect of temperature on Gadwall clutch size at Conaway Ranch is complicated by small samples sizes (<150 nests for all years) and possibly confounded with the remaining covariates that also were supported. However, we still believe these models support a hypothesis that increasing temperatures may play a role in declining clutch sizes in the summer for Gadwall, and could play an increasingly important role in the future when conditions are expected to be warmer.

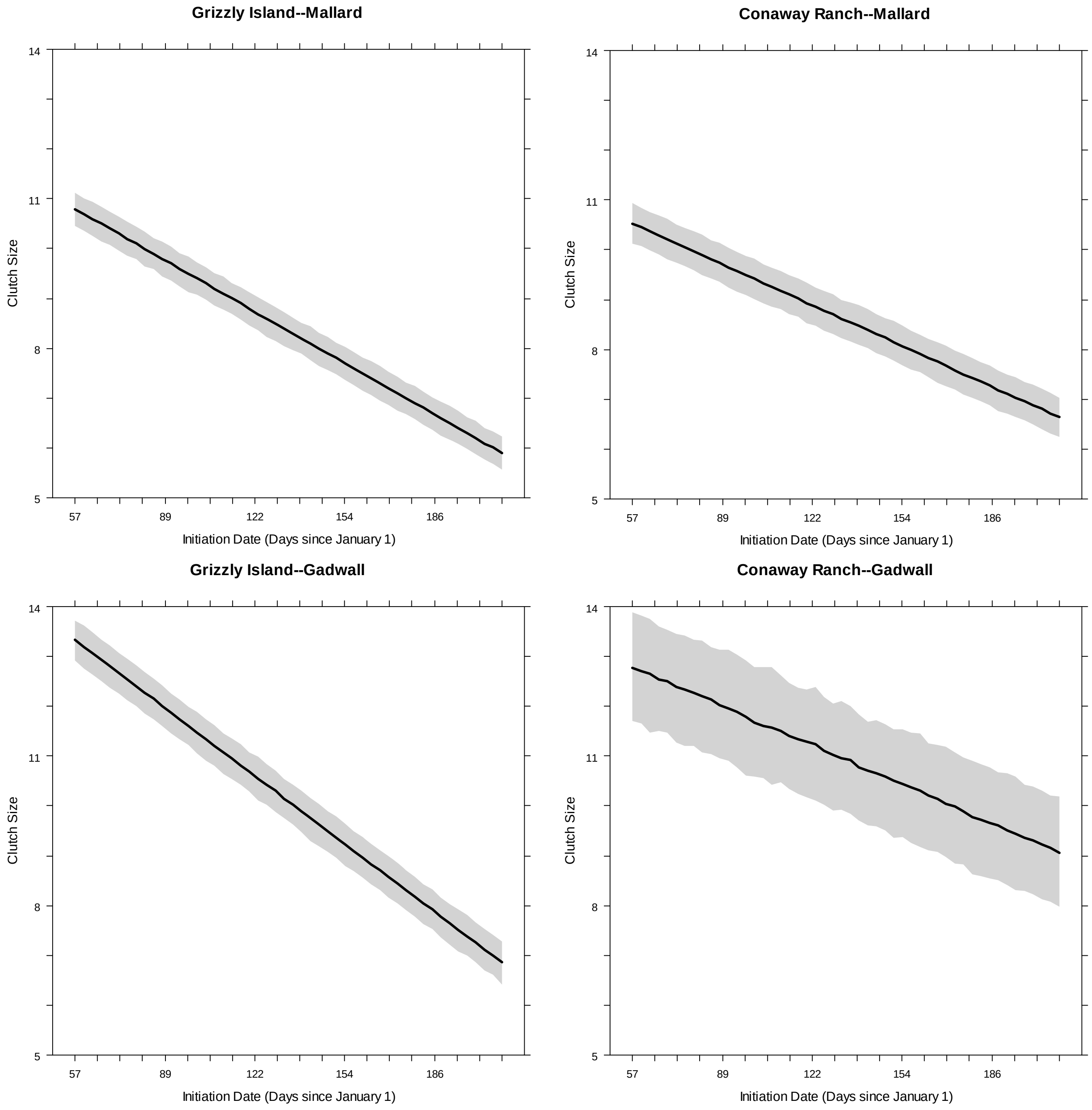


Figure 1. Clutch size declines during the breeding season in California waterfowl. Data are from Mallard and Gadwall nesting at Grizzly Island Wildlife Area (1985-2010) and Conaway Ranch (1991-2006). Results are model-averaged predictions of 1000 simulations, based on AIC_c weights of complete model set. Solid black line represents the prediction mean and the gray shaded area is the 95% credible interval. X-axis represents all dates when a nest was found. In any given year, however, the typical breeding season is only 31-53 (mean 42.8) days long.

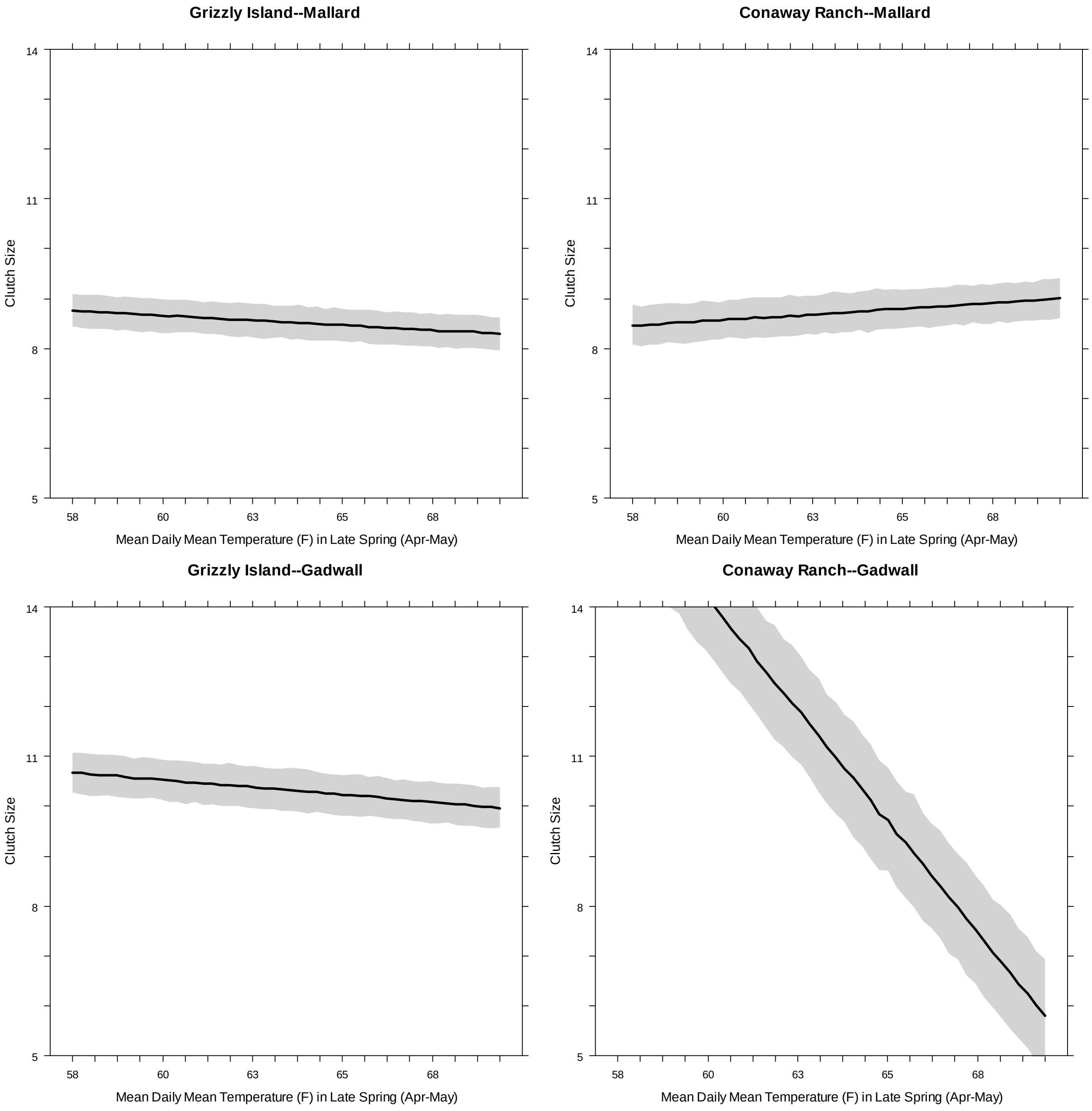


Figure 2. Clutch size in relation to temperatures in the early breeding season. Data are from Mallard and Gadwall nesting in Grizzly Island Wildlife Area (1985-2010) and Conaway Ranch (1991-2006). Results are model-averaged predictions of 1000 simulations, based on AIC_c weights of complete model set. Solid black line represents the prediction mean and the gray shaded area is the 95% credible interval.

Initiation Date, Central Span of Nesting Season, and 10th and 90th Percentile of Nests Initiated

Relationships between breeding phenology variables and weather covariates were highly variable, reflecting both the different systems that Grizzly Island and Conaway Ranch represent as well as the difference in breeding ecology between Mallard and Gadwall.

At Grizzly Island Wildlife Area, Mallard initiated nests earlier when spring temperatures were warmer (**Figure 3**), and decreased nest initiation dates by nearly 2 days for every 1°F increase in average daily temperatures in late spring. In addition, the nesting season length (central span) for Mallard increased approximately 1.75 days for each additional 1 inch of cumulative rain that occurred in late spring (**Figure 3**). In support of these relationships, the date when 10 percent of all nests were initiated (representing the onset of the nesting season) was 1.41 day earlier for each 1°F warmer Grizzly Island Wildlife Area was in late spring. The date when 90 percent of all nests had been initiated (representing the end of nest initiation) also was 1.71 days earlier for every 1°F warmer in spring.

Mallard, and to a lesser extent Gadwall, at Grizzly Island Wildlife Area initiated nests later when there was more precipitation in late winter (1.93 and 0.84 days later for each additional 1 inch of rain in the winter, respectively). For both species, at Grizzly Island Wildlife Area there was a positive relationship between nesting season length and increased pre-breeding precipitation (see **Appendix 2**), however at Conaway Ranch nesting season was not influenced by the amount of precipitation in any season.

Whereas Gadwall at Grizzly Island Wildlife Area responded to increased late winter rains with an increased nesting season duration (0.75 more days per 1 inch of winter rain), our data did not support a similar relationship for Gadwall at Conaway Ranch (**Figure 4**). Likewise, Gadwall responded differently to early spring temperature. Gadwall nesting season length decreased 1 day per 1°F increase in early spring temperatures at Grizzly Island Wildlife Area, but was 3 days longer for each 1°F increase in early spring temperatures at Conaway Ranch (**Figure 4**).

A possible explanation for this contradiction among breeding sites on the influence that temperature has on nesting season length is the negative correlation between cumulative precipitation and mean temperatures in late spring (r= -0.56). Interestingly, this correlation does not exist in early spring (r=-0.02).

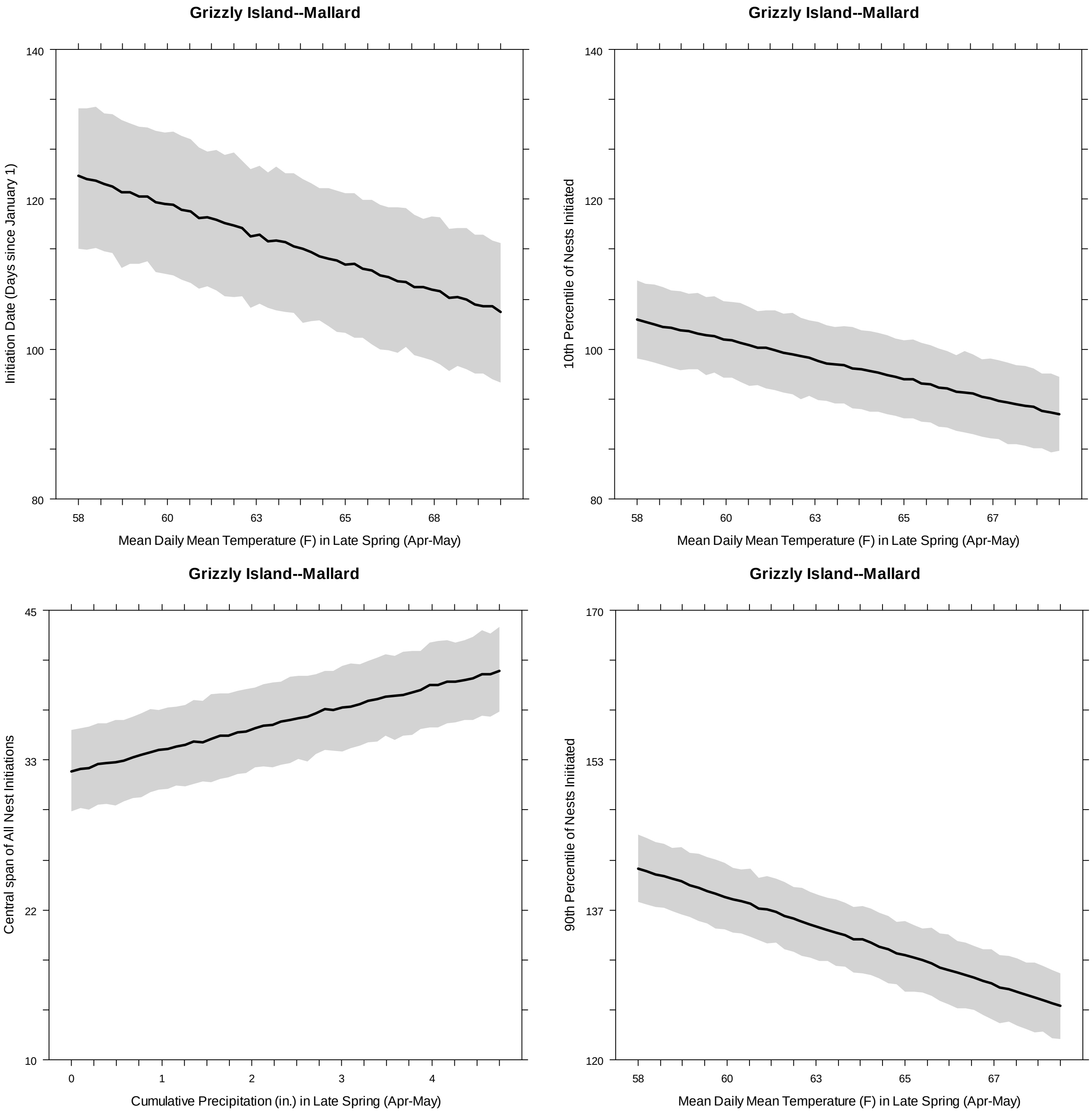


Figure 3. Mallard at Grizzly Island Wildlife Area initiate nests earlier, but may stop nesting sooner when temperatures in spring are warmer. Breeding season for Mallard at Grizzly Island Wildlife Area also is positively associated with early breeding season precipitation. Data are from Mallard nesting in Grizzly Island Wildlife Area (1985-2010). Results are model-averaged predictions of 1000 simulations, based on AIC$_c$ weights of complete model set. Solid black line represents the prediction mean and the gray shaded area is the 95% credible interval.

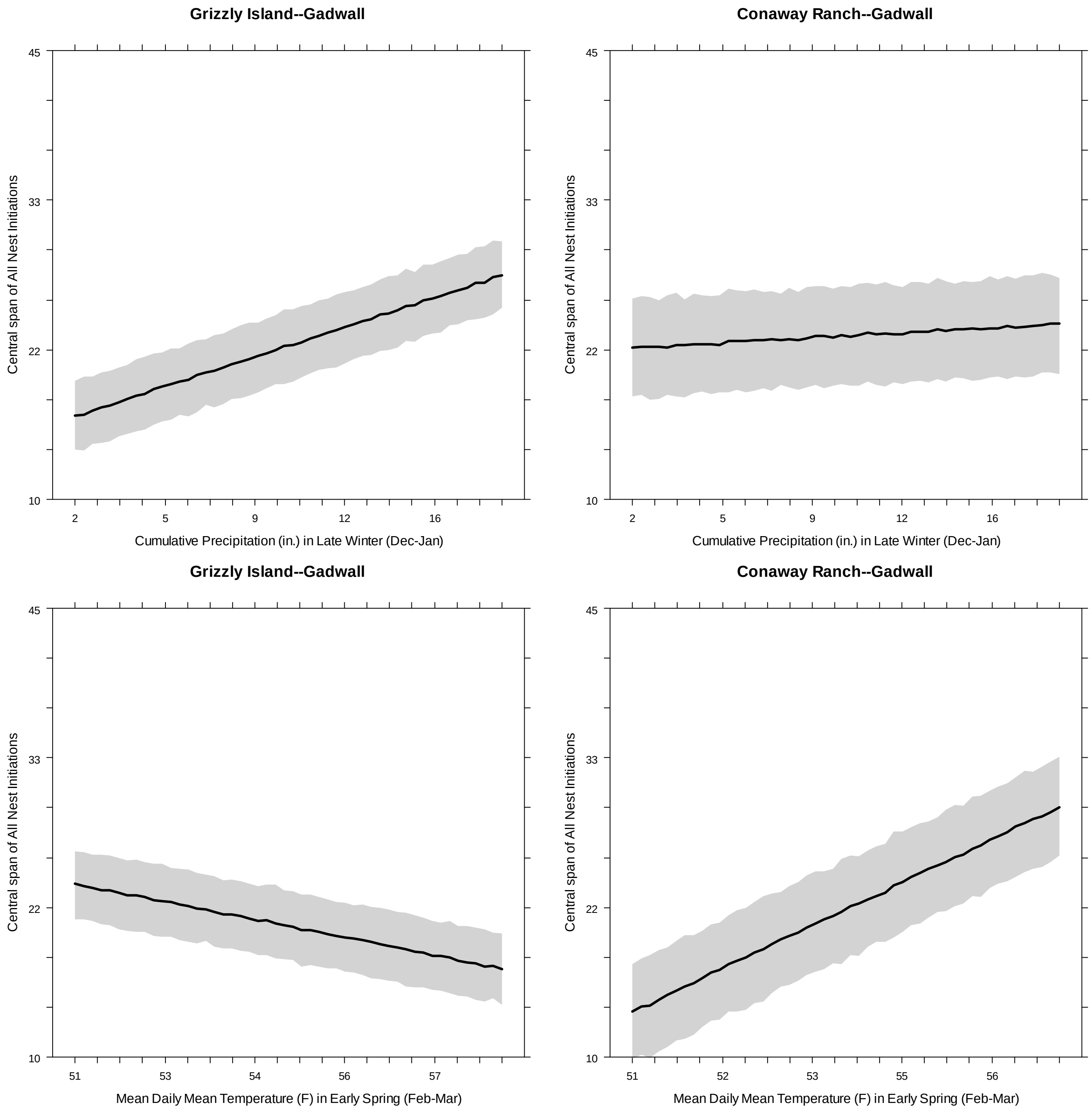


Figure 4. Variation in the relationship of Gadwall nesting season length with seasonal weather conditions. Data are from Gadwall nesting in Grizzly Island Wildlife Area (1985-2010) and Conaway Ranch (1991-2006). Results are model-averaged predictions of 1000 simulations, based on AIC_c weights of complete model set. Solid black line represents the prediction mean and the gray shaded area is the 95% credible interval.

Proportion of Eggs Hatched

A strong negative relationship between proportion of eggs hatched and extreme temperatures (number of days eggs were incubated where outside temperature was ≥95°F) was found in 3 of the 4 analyses for species and site (**Figure 5**). Within our data, 95% of all nests experienced 7 or less days of extreme temperatures during incubation (Grizzly Island Wildlife Area: 0-4 days; Conaway Ranch: 0-13 days) and represented a decrease in egg hatchability of up to 6.1% - 9.6% within our models that showed a negative relationship. In the most extreme case, 13 days of ≥95°F at Conaway Ranch represented a decrease in hatching success of Mallard eggs from 94% to 77% (-17% decrease).

Extending the x-axis out to 30 days does not reflect typical, current environmental conditions. In fact, 95% of all nests experienced 7 or fewer days of extreme temperature during incubation. Thus, the relationship presented here is heavily influenced by only a few nests which experienced such extreme temperature conditions, and may be slightly exaggerated given the reduced sample size used to inform the relationship at the end of the curve. In the future, however, as temperatures are expected to increase, the number of days exceeding 95°F also will increase, and thus the presentation of these extreme examples are warranted.

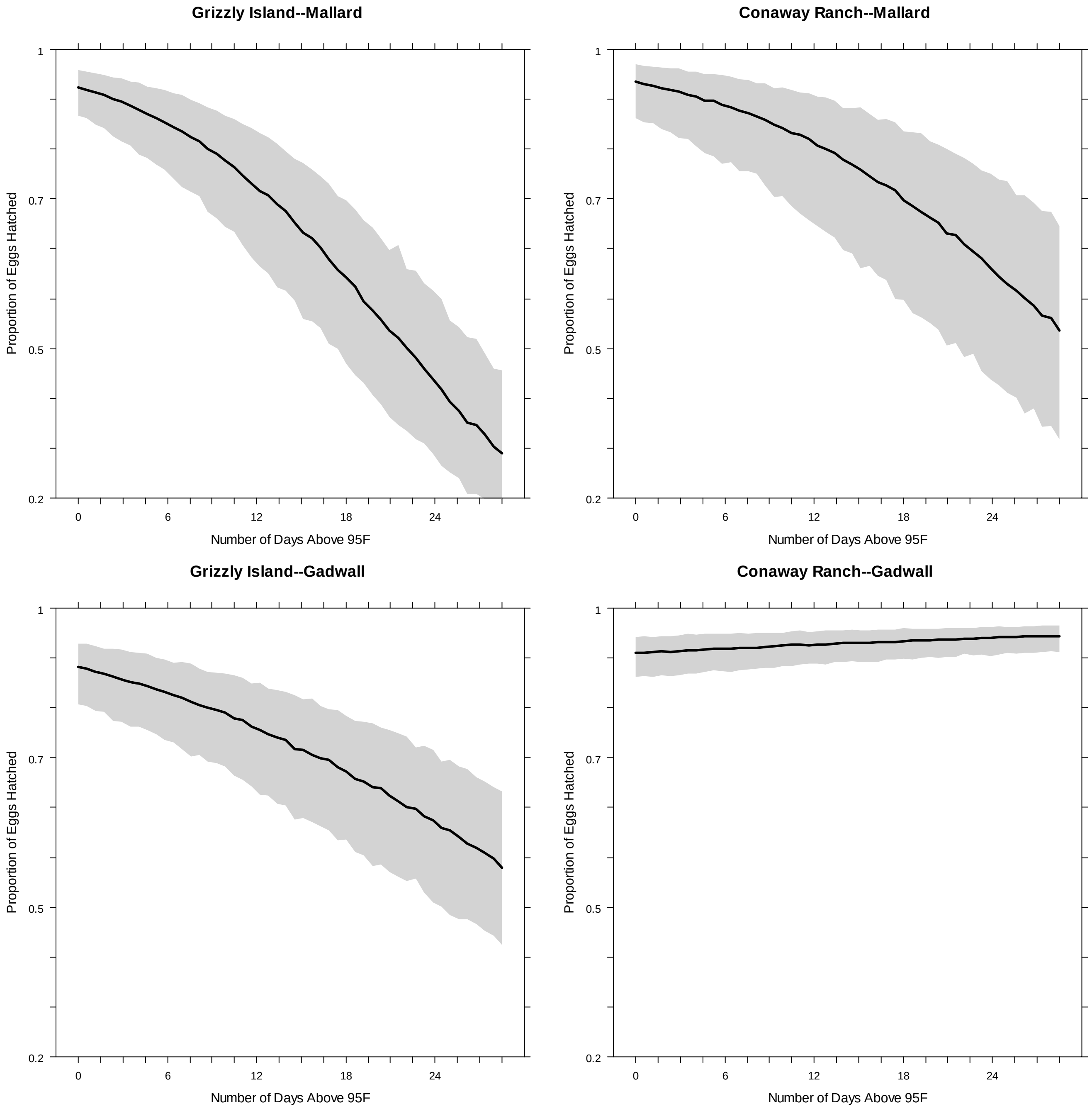


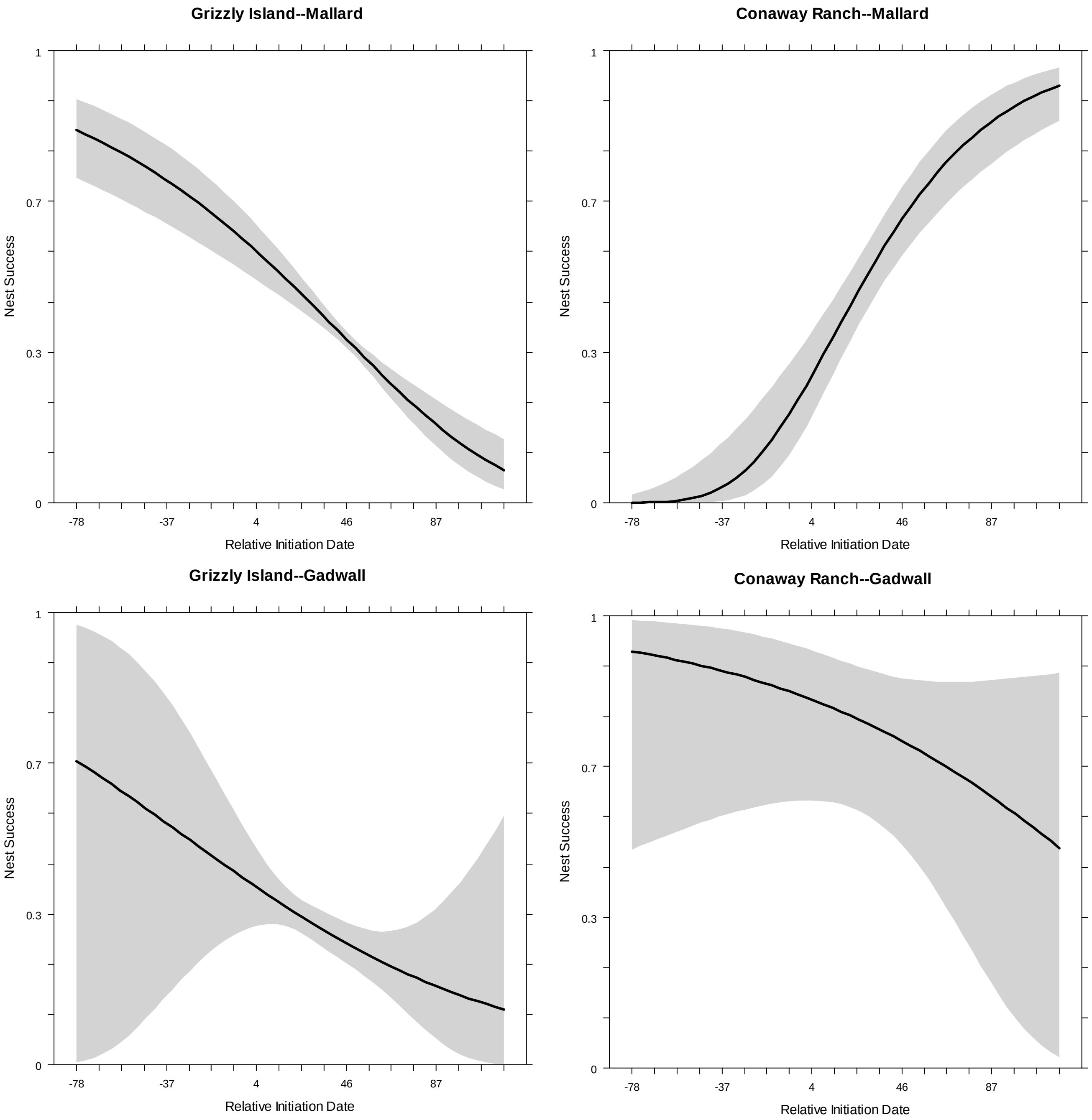
Figure 5. Proportion of eggs hatched from a successful nest decreases as the number of extreme temperatures days during incubation increases. Data are from Mallard and Gadwall nesting at Grizzly Island Wildlife Area (1985-2010) and Conaway Ranch (1991-2006). Results are model-averaged predictions of 1000 simulations, based on AIC_c weights of complete model set. Solid black line represents the prediction mean and the gray shaded area is the 95% credible interval.

Nest Survival

Mallard and Gadwall nest success declined with relative nest initiation date at Grizzly Island Wildlife Area (**Figure 6**). However, Mallard nest success increased and Gadwall nest success decreased with relative nest initiation date at Conaway Ranch (**Figure 6**). The difference in trends for the earlier nesting Mallard among sites are interesting, and suggests that in the Central Valley nest survival increases as the season progresses and more water becomes available as rice fields become flooded later in the season. A similar result of increasing duckling survival with date in the Central Valley was found by G. Yarris (unpublished data), who attributed higher survival of ducklings later in the nesting season to increased rice vegetation cover to conceal ducklings from predators.

Daily nest survival declined with mean daily temperature for each species and site (**Figure 7**). Precipitation metrics, both interval-level as well as seasonal values, were not consistently correlated with nest survival among species or sites and probably reflects the inherently different habitats of Conaway Ranch and Grizzly Island Wildlife Area, as well as the ecological differences between Mallard and Gadwall.

Of note, the base models (models developed prior to incorporation of weather covariates – see Methods section) were very different among regions and species. This suggests there are substantial ecological differences among these sites (such as differences in predator community, land management, etc.) and is an area of active research.


Grizzly Island--Mallard

Conaway Ranch--Mallard

Grizzly Island--Gadwall

Conaway Ranch--Gadwall

Figure 6. The effects of relative initiation date (nest initiation date relative to all other nests of the same species hatched that year at that site) on nest success for Mallard and Gadwall . Data are from Mallard and Gadwall nesting in Grizzly Island Wildlife Area (1985-2010) and Conaway Ranch (1991-2006). Results are model-averaged predictions of 1000 simulations, based on AIC_c weights of complete model set. Solid black line represent the prediction mean and the gray shaded area is the 95% credible interval.

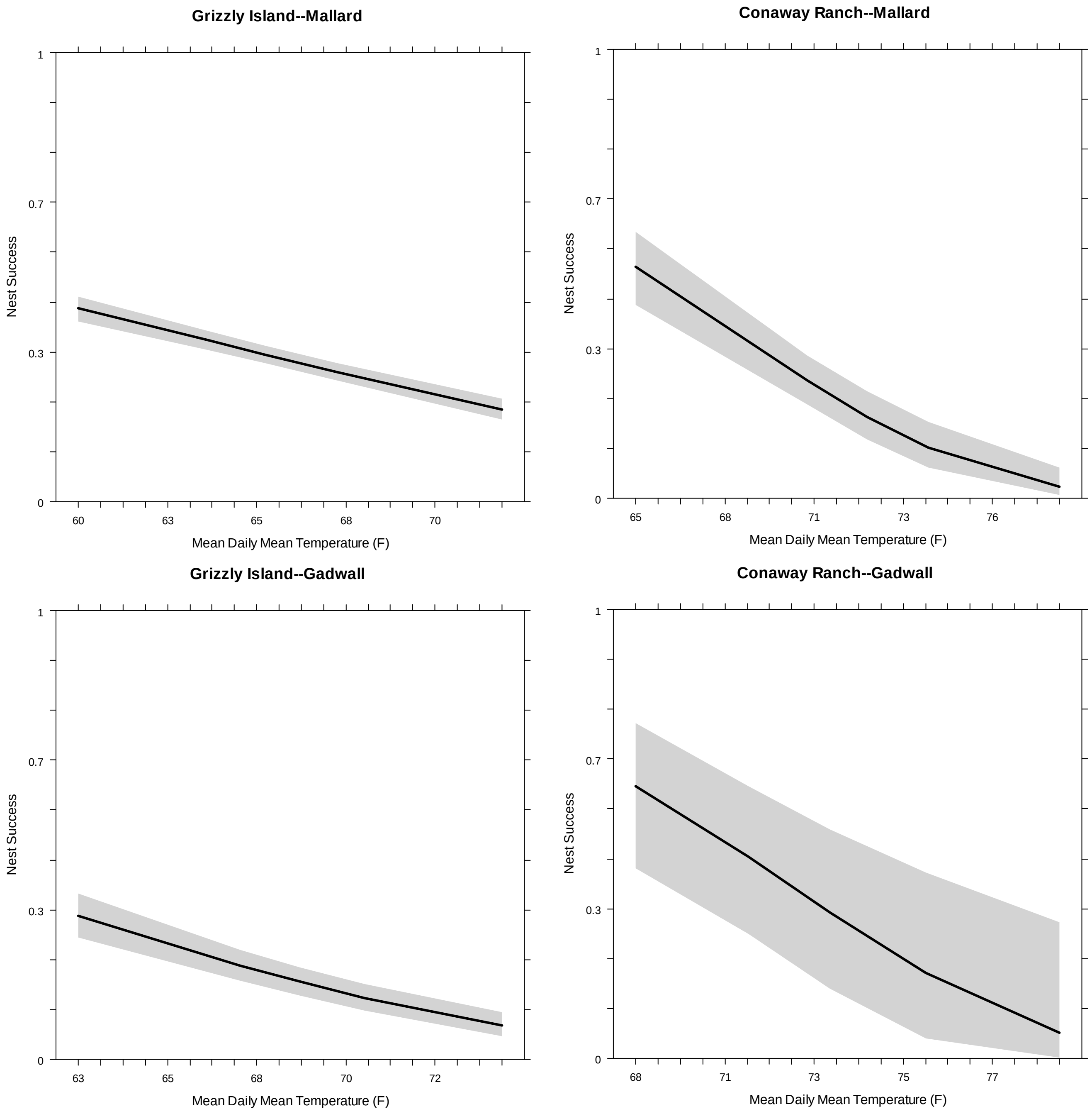


Figure 7. Mallard and Gadwall nest success decrease with average daily temperatures. Data are from Mallard and Gadwall nesting at Grizzly Island Wildlife Area (1985-2010) and Conaway Ranch (1991-2006). Results are model-averaged predictions of 1000 simulations, based on AIC_c weights of complete model set. Solid black line represents the prediction mean and the gray shaded area is the 95% credible interval.

Songbird Results

Nest Survival

Trends

Nest survival for Song Sparrows and Wrentits at Palomarin and for tidal marsh Song Sparrows has increased over the study period, in particular toward the end of the study (>2003; **Figure 8**). A simple linear trend through the model-averaged estimates (across all competing models) for each year shows a positive slope (see **Table 4**).

Table 4. *Simple linear trend analyses of nest survival estimates for Song Sparrows and Wrentits.*

Location	Species	Slope	SE slope	p-value	N	Adj. R-square
Palomarin	Song Sparrow	0.034	0.014	<0.042	12	0.32
	Wrentit	0.033	0.011	<0.015	13	0.41
Tidal marshes	Song Sparrow	0.012	0.005	<0.024	13	0.35

Besides the pattern in slopes and better survival toward the end of the study, little else in the patterns of nest survival by year seems to be similar between the species and regions. There is a spike in survival in 1999 for Song Sparrow at Palomarin, but nothing similarly notable in the Wrentit data. The same is the case when comparing Song Sparrow nest survival data between Palomarin and the North Bay tidal marshes. The latter show a less pronounced increase in nest survival over time, but the details of the pattern does not resemble that of the Palomarin population.

The overall increase in survival may be due to milder weather conditions and increasing food supplies at both locations. A detailed analysis of climatic covariates follows below. The significantly lower survival probabilities of nests at the tidal marshes (simple linear model with location as factor using Palomarin as reference, effect of tidal marsh location = -0.368, std. error = 0.048, $p < 0.001$, $n = 24$, adjusted $R^2 = 0.74$) is most likely due to an abundant and diverse nest predator community, habitat fragmentation, and flooding events.

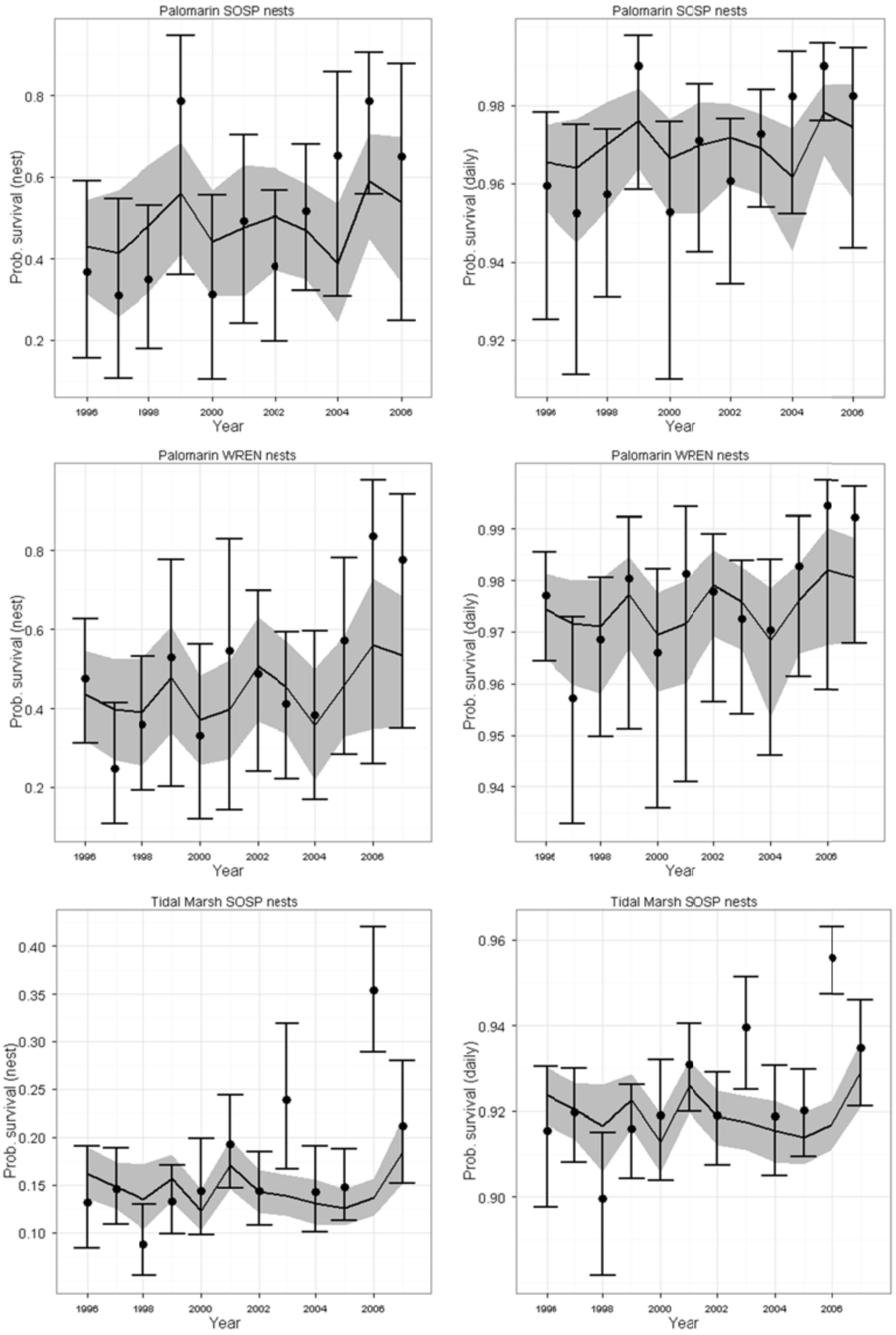


Figure 8. Probability of nest survival (1st column) and daily survival (2nd column) for nests of Song Sparrow (SOSP) and Wrentit (WREN) at Palomarin and for Song Sparrow in tidal marshes of the North Bay. Dots with error bars (standard errors) are the observed survival probabilities; the line with the gray shade (standard errors) shows the model averaged predictions.

These results suggest that management actions are not necessary at this time for Song Sparrows and Wrentits at Palomarin. Had we detected the opposite pattern, a significant decline in nest survival, research and management actions would be warranted. However, it is important to consider breeding demographic parameters in addition to nest survival. For example, Song Sparrows are significantly declining in abundance at Palomarin (PRBO, unpublished data) which may warrant management actions that aim to increase their populations.

Despite the encouraging trend, nest survival in the tidal marshes was very low. Management actions should consider nest predator control in the short-term and increasing the amount of tidal marsh habitat in the short- to long-term.

Effect of Bioyear Precipitation

We assumed that precipitation during the rainy season (measured as total October to March precipitation and hereafter "bioyear" rainfall) would directly correlate with vegetation growth and invertebrate abundance. The larger the growth, the better the year for nest survival, as there would be more vegetative cover concealing the nests and perhaps greater food availability.

Our hypothesis seems not to be supported by the data. **Figure 9** shows a trend for Song Sparrows and Wrentits at Palomarin, but it was not significant in any of the competing models for these species at that location (see **Appendix 2**). The pattern of response was positive for Song Sparrow and negative for Wrentit at Palomarin, and in the tidal marshes it was flat. Despite the fact of its non-significance, bioyear precipitation was present in competing models for all species and locations, evidencing some role in nest survival.

These results are in agreement with prior estimates from Palomarin data (Chase et al. 2005), who found a significant positive relationship between daily nest survival probabilities and the quadratic of bioyear precipitation. Factors other than bioyear precipitation may be more important in determining the survival of nests at Palomarin during the period we analyzed. This may be the case if there is always high rainfall and small variations in vegetation growth have little overall effect. For example, density-dependent effects may be more important in driving the survival of nests. Daily survival values are high for both the Song Sparrow and the Wrentit during the period of this study. At the tidal marshes, the lack of suitable nesting vegetation would diminish the effect of this variable. Thus, the lack of significant effects such as those found by Chase et al. (2005) may be explained by climate differences between the periods analyzed. Their dataset included 8 years of below-average dry weather (6 of them below the 34-year average), and years 1996 to 2000 had all high nest survival (see Figure 5 in Chase et al. 2005).

The apparent negative effect on Wrentits may also be explained by other factors with more important influence on survival than those we considered, such as density-dependent effects. Nevertheless, the trend is in agreement with DeSante and Geupel's (1987) report on low hatch-year counts after heavy bioyear rainfall.

The effect of bioyear precipitation may be more complex than just increasing vegetative cover and productivity, or negative effects, as speculated by DeSante and Geupel (1987). Its effects remain still unclear and more detailed studies will be required to properly provide management recommendations. However, the contrast with the Chase et al. (2005) study seems to suggest that drought may have a detrimental effect on survival.

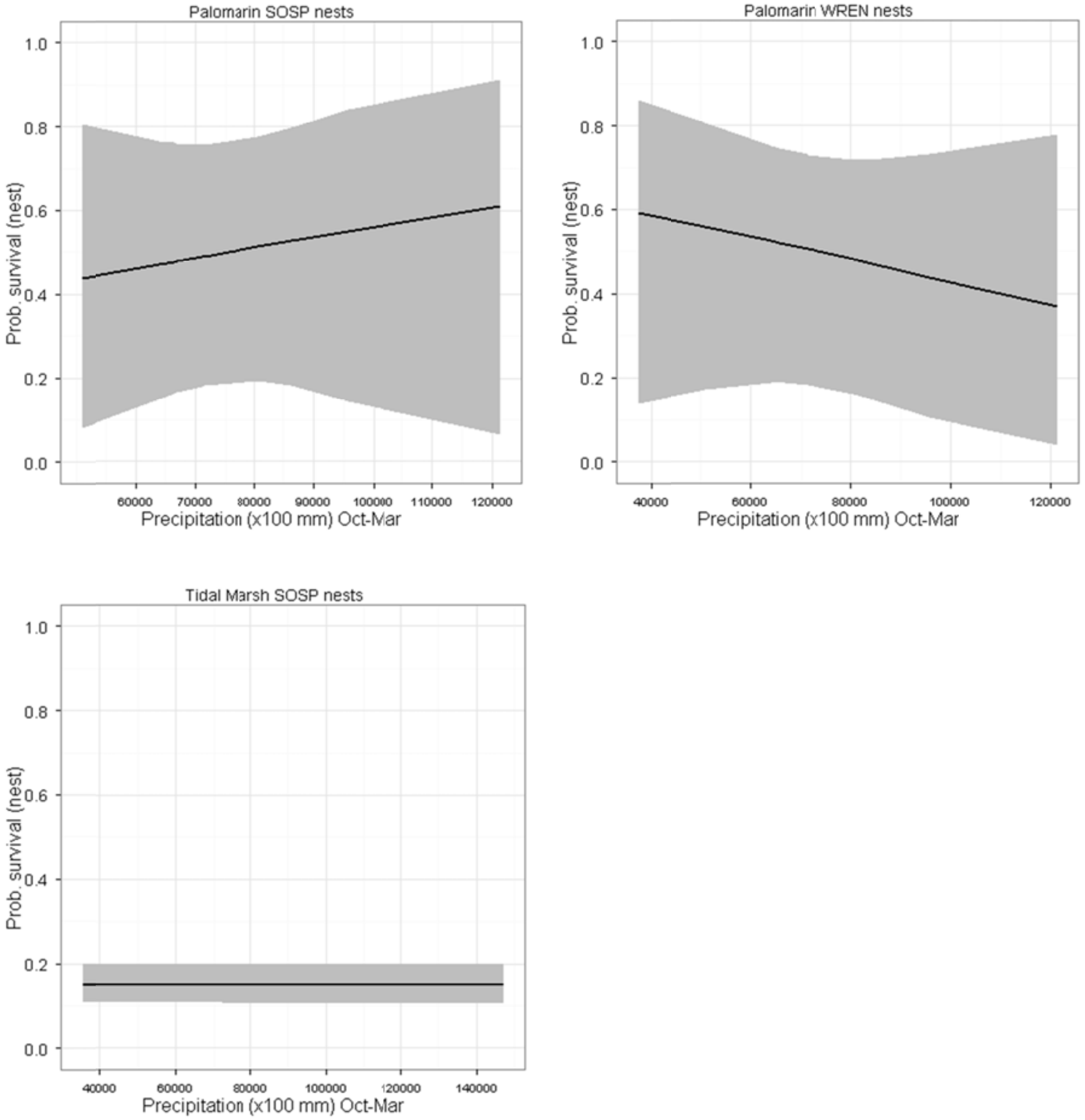


Figure 9. Effect of total bioyear precipitation on the probability of nest survival for nests of Song Sparrow and Wrentit at Palomarin and at tidal marshes of the North Bay. Graphs show the model-averaged effects from all competing models for each species and location.

Effect of Precipitation in Immediately Prior Months

We evaluated the effect of precipitation as a proxy variable for food availability, considering total precipitation for the month prior to hatching, the total for the 2 prior months and 3 prior months. We included only one of these variables per model, and these were not included in models that also included bioyear precipitation. We hypothesized that an increase in precipitation, represented by one of these precipitation parameters, may correlate with an increase in food productivity and, thus, higher survival.

Only precipitation in the prior month was present in competing models for all three species and locations, and it was a significant, but small effect in some competing models for the tidal marsh Song Sparrows (**Figure 10-12**). Precipitation in the three months prior to hatching showed a significant effect in some of the competing models for the Wrentit at Palomarin. The patterns at Palomarin for Song Sparrow and Wrentit are very similar to those of bioyear precipitation. Overall, no discernible effects were observed at Palomarin that we could clearly attribute to months immediately prior to hatching. Bioyear precipitation (see above) may better account for increased productivity, the effect we sought to account for with these parameters.

Precipitation during the prior three months for the tidal marsh Song Sparrow does show a significant positive trend and opposite to that of bioyear, possibly suggesting increased food productivity. Thus, the tidal marsh Song Sparrow's nest survival may be favorable when there is high late winter/early spring precipitation.

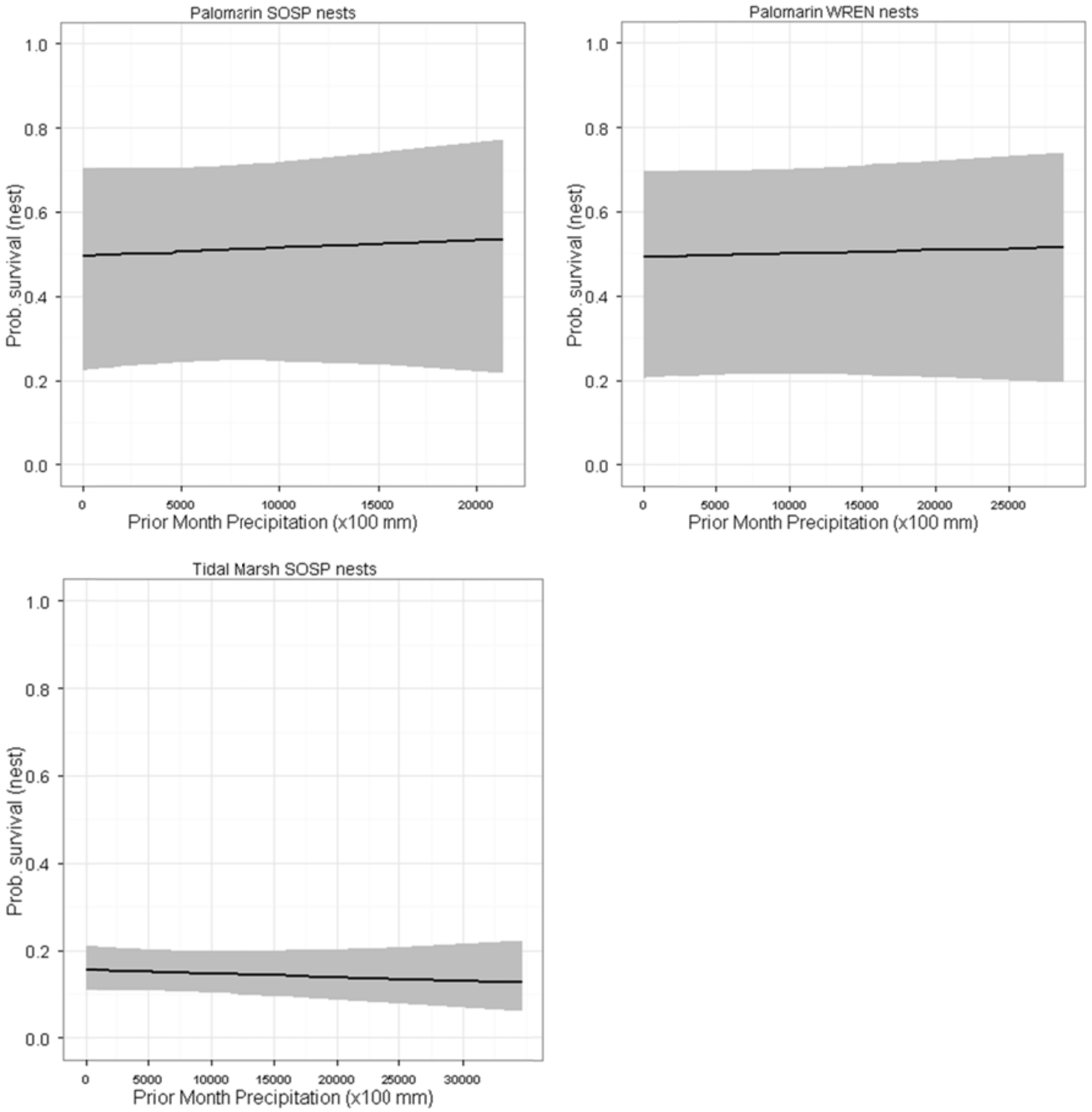


Figure 10. Effect of total precipitation for the month prior to hatching on the probability of daily survival for nests of Song Sparrow and Wrentit at Palomarin and at tidal marshes of the North Bay. Graphs show the model-averaged effects from all competing models for each species and location. Some competing models for tidal marsh Song Sparrow showed a significant effect.

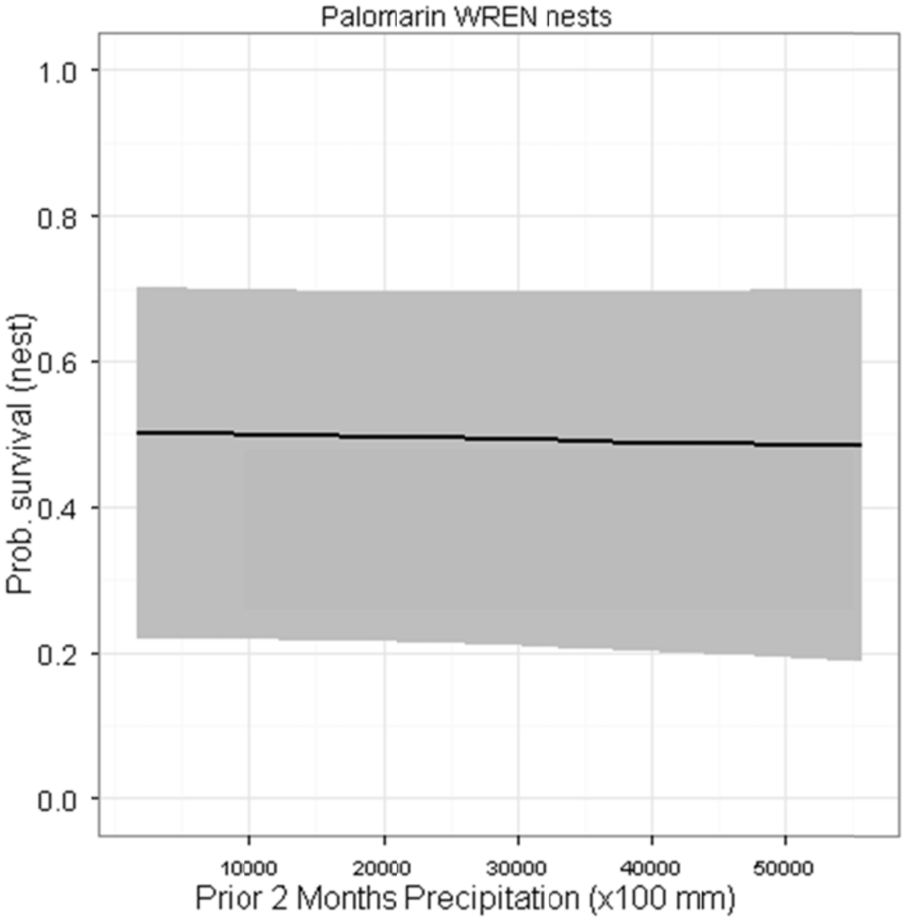


Figure 11. Effect of total precipitation for the two months prior to hatching on the probability of daily survival for nests of Song Sparrow and Wrentit at Palomarin and at tidal marshes of the North Bay. Graphs show the model-averaged effects from all competing models for each species and location. This variable present only in competing models for Wrentit at Palomarin and showed no significant effects in any model.

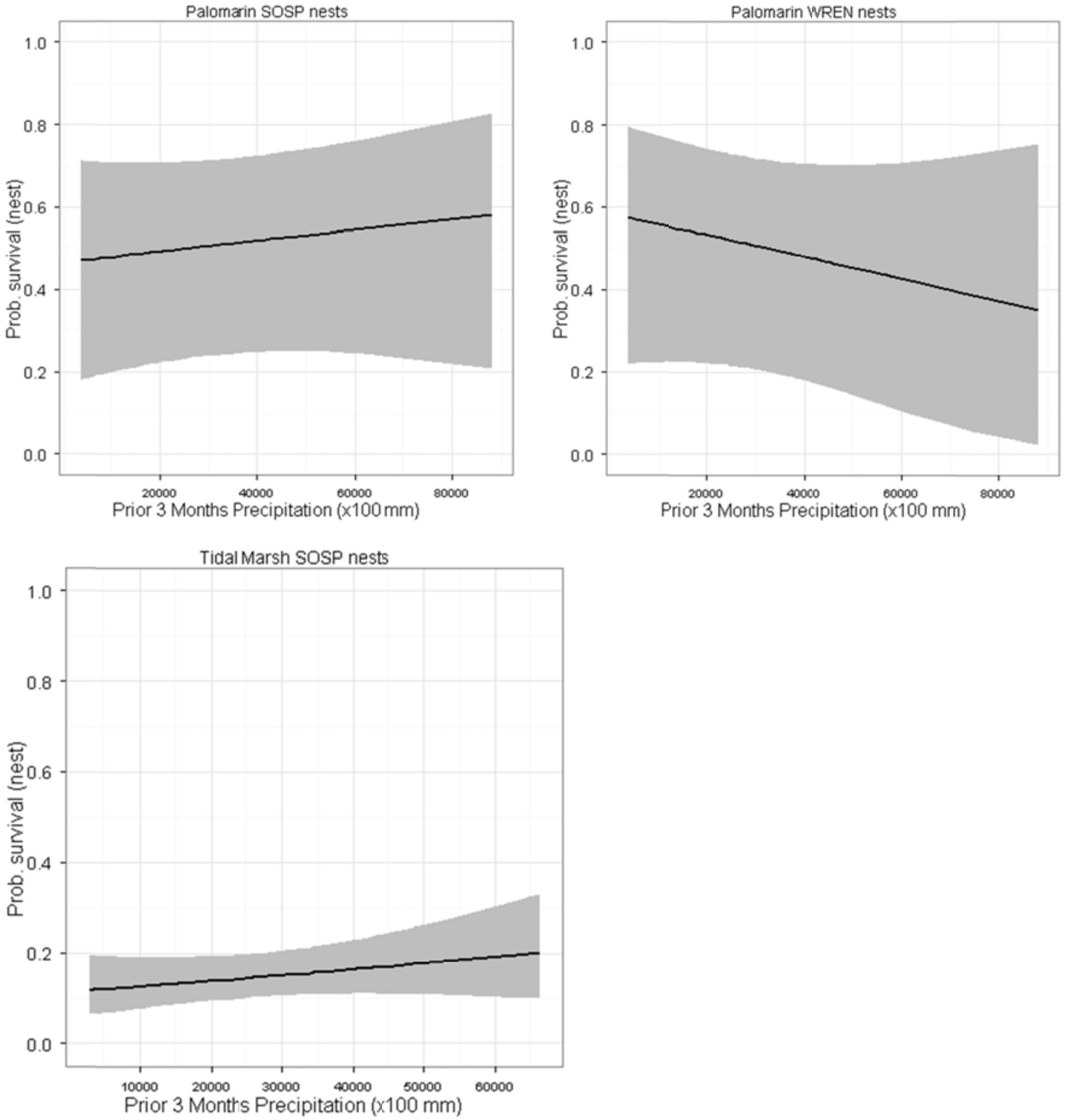


Figure 12. Effect of total precipitation for the three months prior to hatching on the probability of daily survival for nests of Song Sparrow and Wrentit at Palomarin and at tidal marshes of the North Bay. Graphs show the model-averaged effects from all competing models for each species and location. Some competing models for the Wrentit at Palomarin and the tidal marsh Song Sparrow showed a significant effect.

Effect of Hatch-Month Precipitation

We hypothesized that precipitation during the hatch month may have a detrimental effect on survival of nests. We suspect that heavy rainfall may cause flooding of the tidal marshes, which is an important cause of mortality and nest abandonment in our data. The effect of precipitation at Palomarin is unclear. We included the variable in our analyses to see if there was an effect of heavy rains during the hatching month, and it was selected among the competing models for the Wrentit and tidal marsh Song Sparrow, but not for the Song Sparrow at Palomarin.

Hatch-month precipitation was among the variables in competing nest survival models for the Wrentit at Palomarin and the Song Sparrow in tidal marshes. For Wrentits the overall effect was positive, perhaps an indication of increased food productivity (**Figure 13**).

Notably, it had the hypothesized negative significant effects in some of the competing models for tidal marsh Song Sparrow nest survival. This may be due to a possible correlation between hatch-month precipitation and flooding of the tidal marshes.

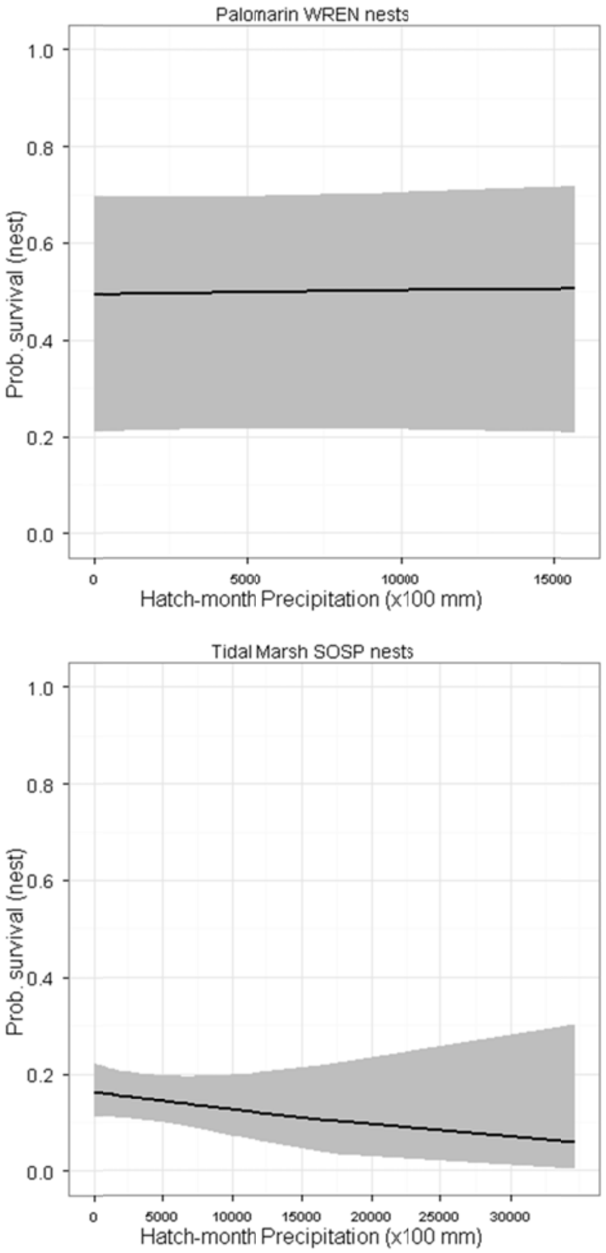


Figure 13. Effect of total precipitation for the hatch-month on the probability of daily survival for nests of Wrentit at Palomarin and at tidal marshes of the North Bay. Graphs show the model-averaged effects from all competing models for each species and location. Some competing models for the tidal marsh Song Sparrow showed a significant effect.

Effects of Temperature

We evaluated the effects of minimum and maximum temperatures during the hatch month and up to three months prior. We hypothesized that temperature (either or both monthly minima and maxima) would positively correlate to food production and thus affect nest survival. Each model, among the 73 evaluated, contained only one of the temperature variables, so only one of them is present in each resulting competing model.

All temperature parameters were present in competing models for the species, but not all of them in a single set of models for a species and location. Song Sparrows at Palomarin, for example, included all but minimum temperature during the hatch month among its resulting competing models. The minimum temperature on hatch month was present in competing models for the Wrentit at Palomarin and the tidal marsh Song Sparrow, and it was a significant effect in models in both cases. Additionally, competing models for the tidal marsh Song Sparrow showed significant effects for minimum temperature for the two months prior to hatching, maximum temperature during the hatch-month, and maximum temperature on the two and three months prior to hatching.

Notably, the data validates our hypothesis only for the Wrentit at Palomarin (**Figure 14**). Temperature during the hatch month has an overall negative effect on Song Sparrow nest survival, in particular in the tidal marshes. But it is important to note, too, that temperatures at the tidal marshes vary nearly twice as widely as at Palomarin (maxima for the tidal marshes vary from 15 to 30°C, whereas only 14 to 22°C at Palomarin), and the maxima (that correlate with minima) may reflect high temperature stress for nesting Song Sparrows in the tidal marshes. This thermal stress may be more important if there is no suitable vegetation cover, or the individuals are under duress to reproduce in marginally suitable habitat, or both.

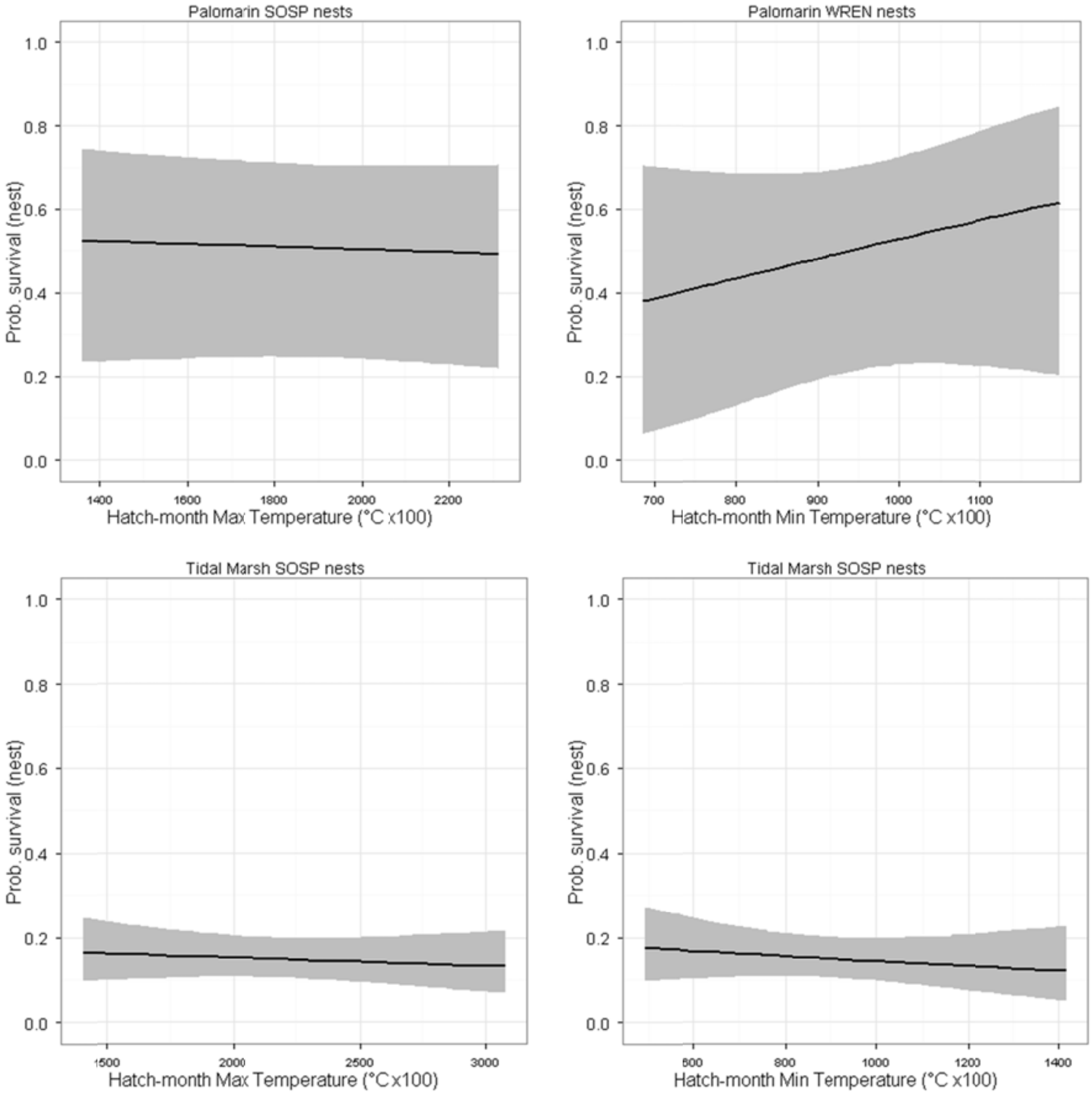


Figure 14. Effect of minimum and maximum temperature for the hatch month on the probability of daily survival for nests of Song Sparrow and Wrentit at Palomarin and at tidal marshes of the North Bay. Graphs show the model-averaged effects from all competing models for each species and location. Some competing models for Wrentit at Palomarin and tidal marsh Song Sparrow showed a significant effect of minimum temperature, and some models for the tidal marsh Song Sparrow showed a significant effect of maximum temperature.

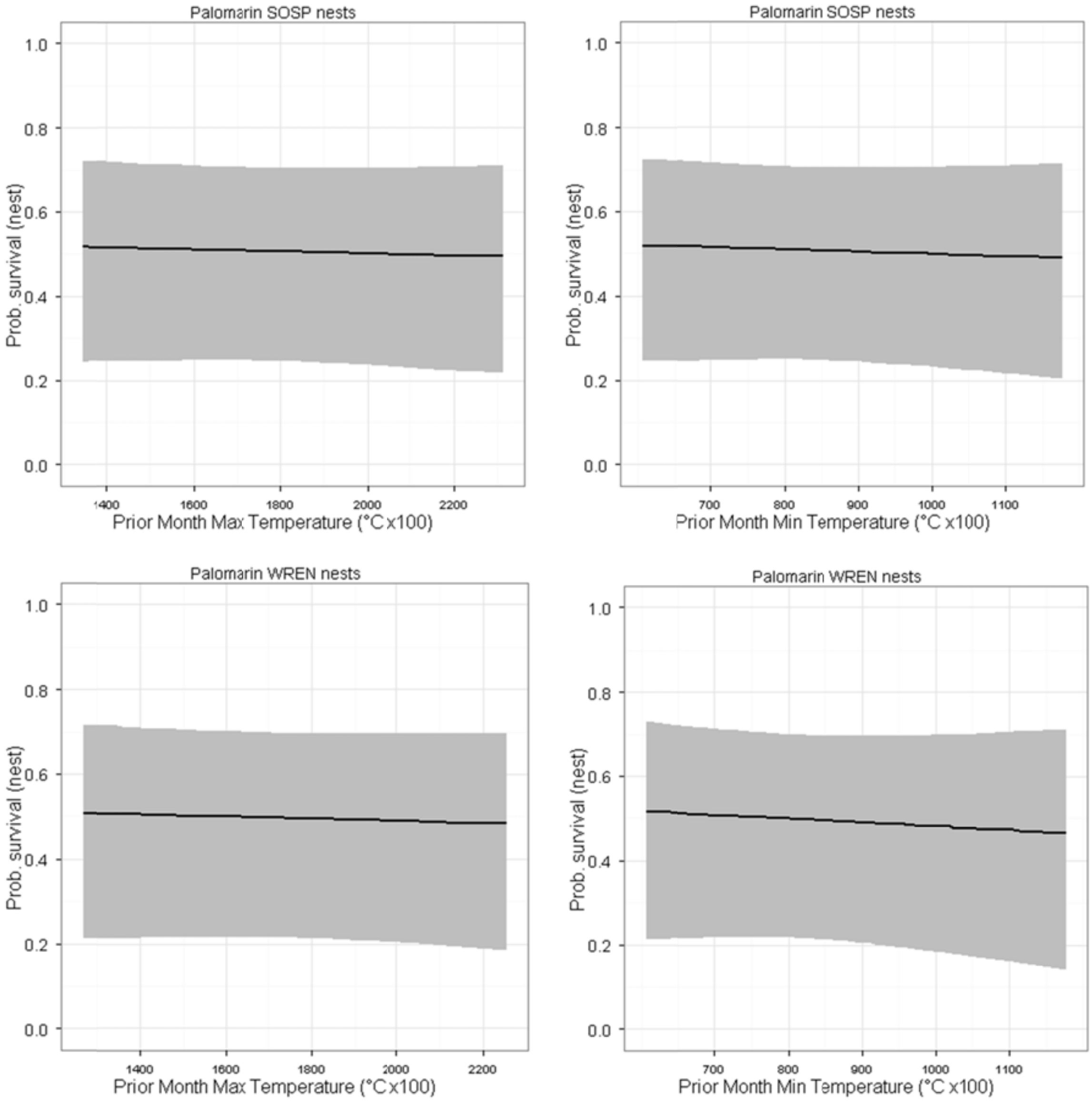
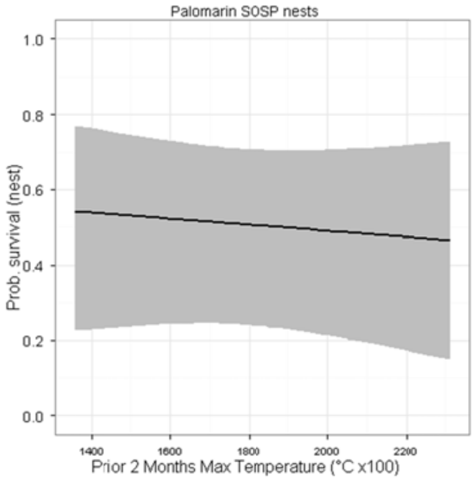
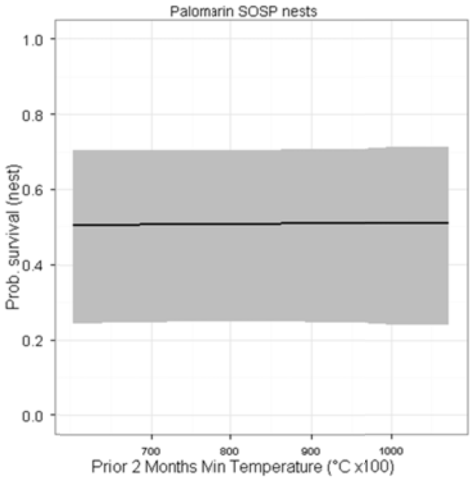
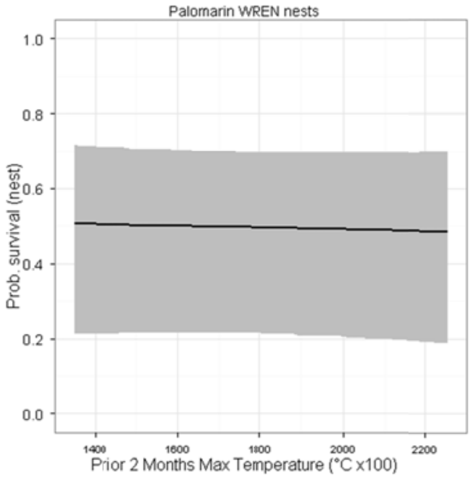
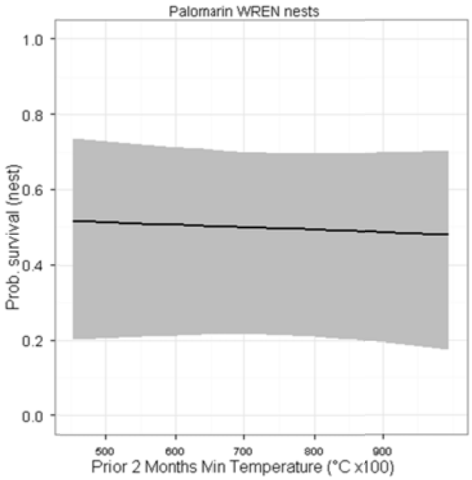


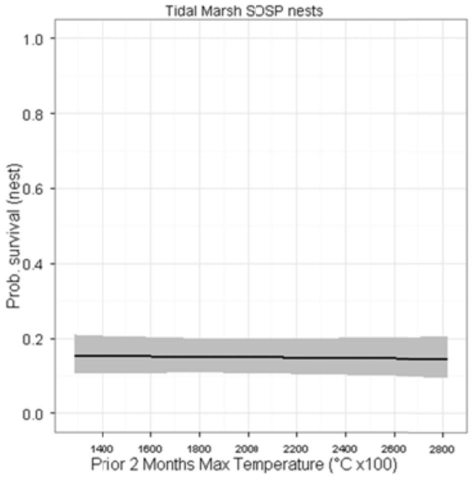
Figure 15. Effect of minimum and maximum temperature for the month prior to hatching on the probability of daily survival for nests of Song Sparrow and Wrentit at Palomarin and at tidal marshes of the North Bay. Graphs show the model-averaged effects from all competing models for each species and location.


Palomarin SOSP nests
Prob. survival (nest)
1.0
0.8
0.6
0.4
0.2
0.0
1400
1600
1800
2000
2200
Prior 2 Months Max Temperature (°C x100)


Palomarin SOSP nests
Prob. survival (nest)
1.0
0.8
0.6
0.4
0.2
0.0
700
800
900
1000
Prior 2 Months Min Temperature (°C x100)


Palomarin WREN nests
Prob. survival (nest)
1.0
0.8
0.6
0.4
0.2
0.0
1400
1600
1800
2000
2200
Prior 2 Months Max Temperature (°C x100)


Palomarin WREN nests
Prob. survival (nest)
1.0
0.8
0.6
0.4
0.2
0.0
500
600
700
800
900
Prior 2 Months Min Temperature (°C x100)


Tidal Marsh SOSP nests
Prob. survival (nest)
1.0
0.8
0.6
0.4
0.2
0.0
1400
1600
1800
2000
2200
2400
2600
2800
Prior 2 Months Max Temperature (°C x100)

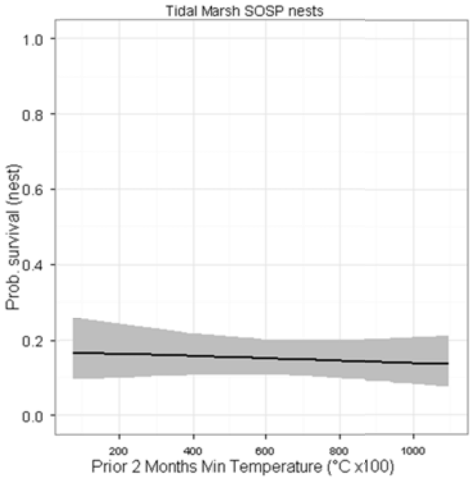

Tidal Marsh SOSP nests
Prob. survival (nest)
1.0
0.8
0.6
0.4
0.2
0.0
200
400
600
800
1000
Prior 2 Months Min Temperature (°C x100)

Figure 16. Effect of minimum and maximum temperature for the two months prior to hatching on the probability of daily survival for nests of Song Sparrow and Wrentit at Palomarin and at tidal marshes of the North Bay. Graphs show the model-averaged effects from all competing models for each species and location. Some competing models for the tidal marsh Song Sparrow showed a significant effect of minimum and maximum temperature.

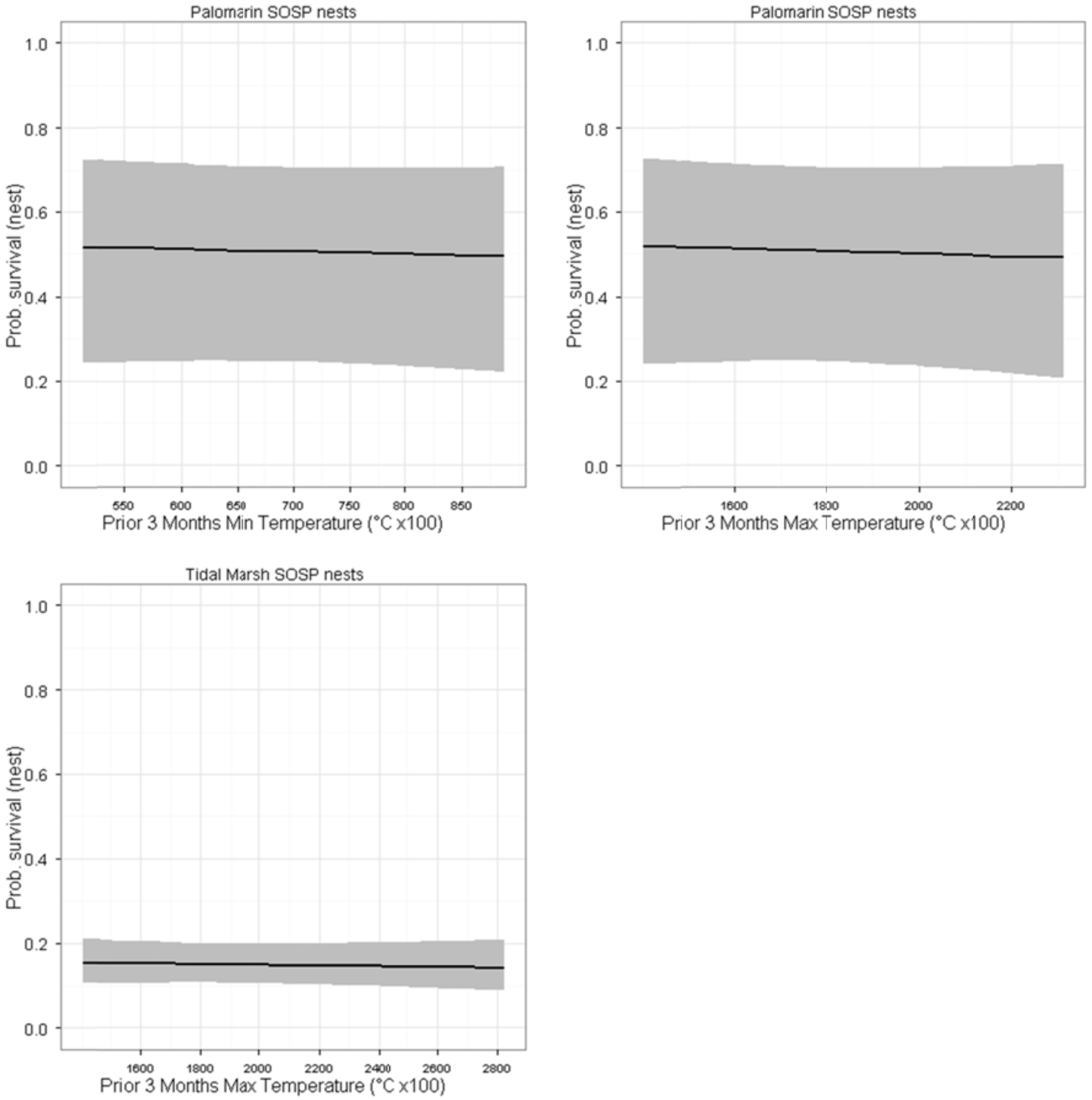


Figure 17. Effect of minimum and maximum temperature for the three months prior to hatching on the probability of daily survival for nests of Song Sparrow and Wrentit at Palomarin and at tidal marshes of the North Bay. Graphs show the model-averaged effects from all competing models for each species and location. Some competing models for the tidal marsh Song Sparrow showed a significant effect of maximum temperature.

Date of First Arrival

Date of first arrival patterns show only significant trends for MacGillivray's Warbler, Northern Rough-winged Swallow and Warbling Vireo (**Figure 18** – regression lines shown only for those species with a significant trend). Of these three species, only the Vireo has enough data to properly assess a trend. The Warbling Vireo has been decreasing in abundance at Palomarin (Gardali et al. 2000, Gardali and Jaramillo 2001), so the observed trend may be due to declining numbers (Miller-Rushing et al. 2008).

We attempted to fit the data to models that included total values for large-scale climate indices for all but one species (Northern Rough-winged Swallow – the species had arrival date estimates for <5 years). Below we report the fits for the resulting best model for each large-scale climate index and each species.

Significant relationships between large-scale climate index variables and day of first arrival were found for three Neotropical migrant species. Barn Swallow arrival data related negatively with the cumulative monthly value of the Northern Oscillation Index. In particular, large negative index values correlate with later arrival dates. The large negative index values are usually associated with El Niño events and high upper ocean temperatures along the North American west coast (Schwing et al. 2002). Therefore, the data seem to indicate later arrival dates during El Niño event years.

Black-headed Grosbeak arrival data show a negative correlation with ENSO values, but this is mainly due to early arrival dates at index values >80. That is, the effect seems to be the opposite of that observed in Barn Swallows: Black-headed Grosbeak individuals tend to arrive earlier during El Niño events. These events are characterized by higher surface temperatures in the Northeastern Pacific.

The Pacific-slope Flycatcher arrival data correlates negatively with the Pacific Decadal Oscillation and positively with the Southern Oscillation Index. SOI values correlate with climate patterns in the Tropical Southwestern Pacific that are not strongly related to Northeastern Pacific weather (Schwing et al. 2001). This suggests possible effects at wintering grounds. The PDO is largely an index of the North Pacific, with little relation to tropical patterns, and lasts several decades, rather than months (Mantua et al. 1997). The data analyzed here are part of a cooling PDO, which translates to colder North Pacific Sea temperatures. Together with the SOI results, this suggests late arrivals during warmer years.

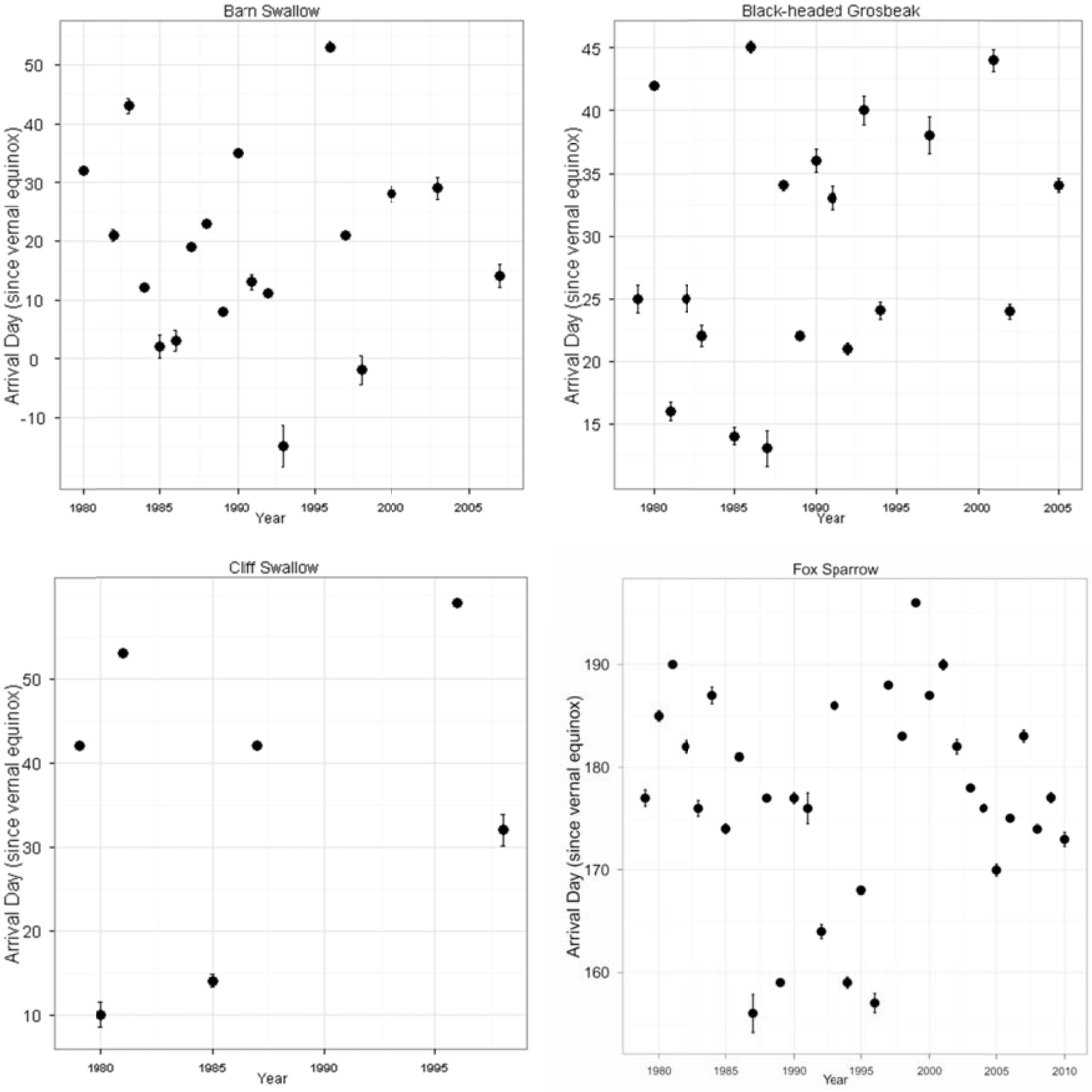


Figure 18. Estimates of day of first arrival for 15 species of songbird, including 12 Neotropical and 3 Nearactic migrants. Regression lines are shown for the three species with significant slopes; shaded areas are the standard errors of the regression.

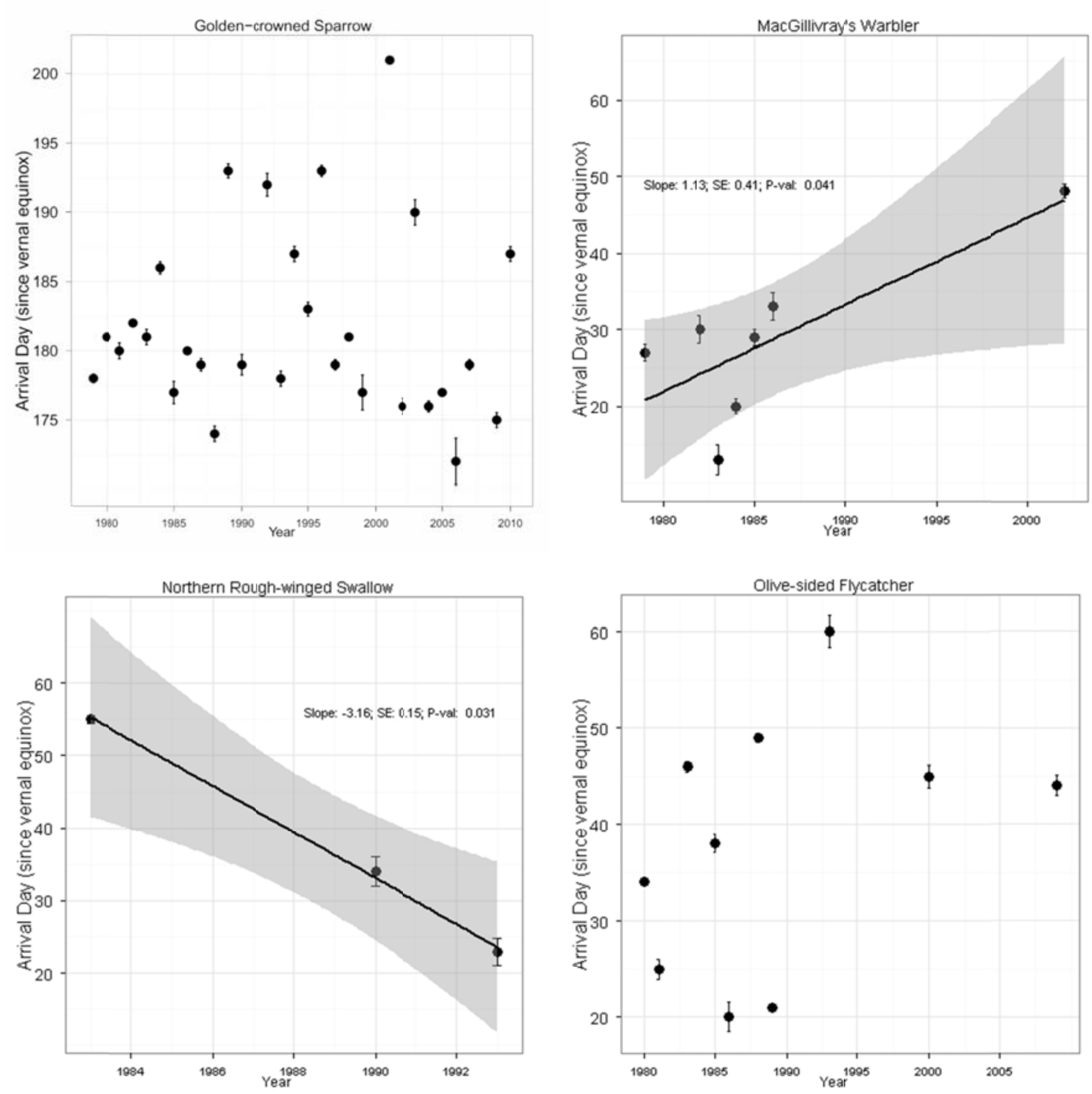


Figure 18 (continued). Estimates of day of first arrival for 15 species of songbird, including 12 Neotropical and 3 Nearactic migrants. Regression lines are shown for the three species with significant slopes; shaded areas are the standard errors of the regression.

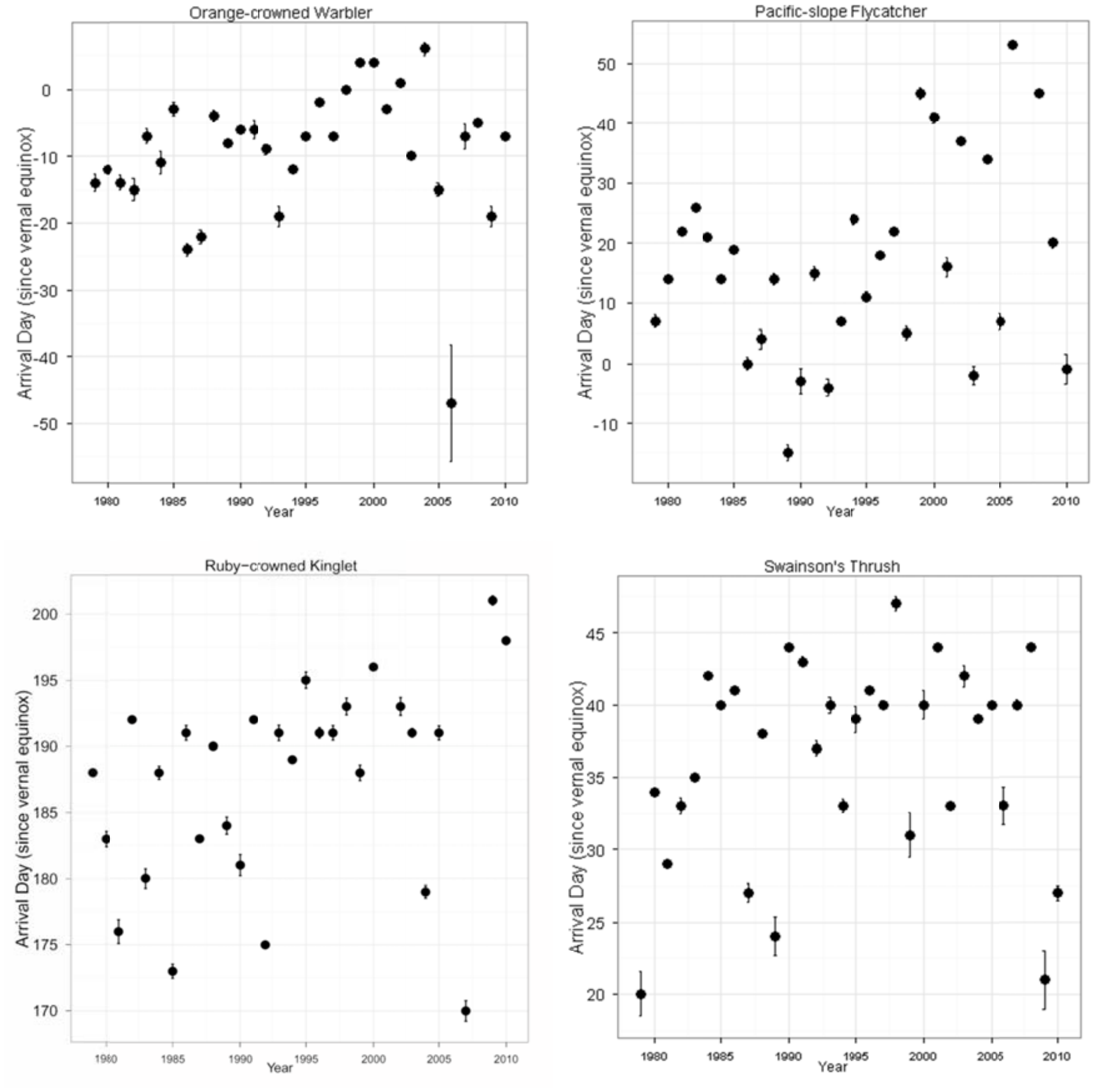


Figure 18 (continued). Estimates of day of first arrival for 15 species of songbird, including 12 Neotropical and 3 Nearactic migrants. Regression lines are shown for the three species with significant slopes; shaded areas are the standard errors of the regression.

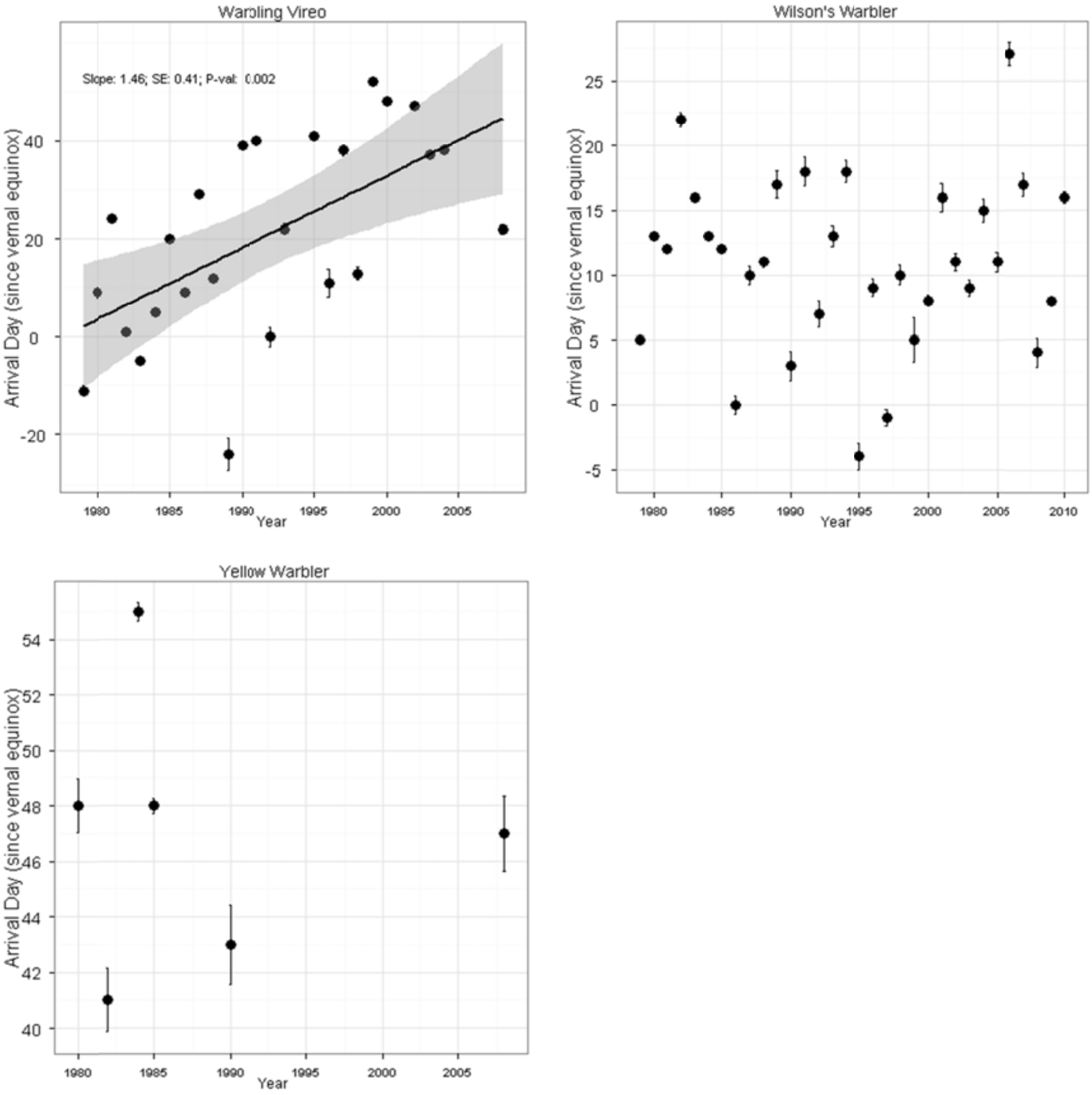


Figure 18 (continued). Estimates of day of first arrival for 15 species of songbird, including 12 Neotropical and 3 Nearactic migrants. Regression lines are shown for the three species with significant slopes; shaded areas are the standard errors of the regression.

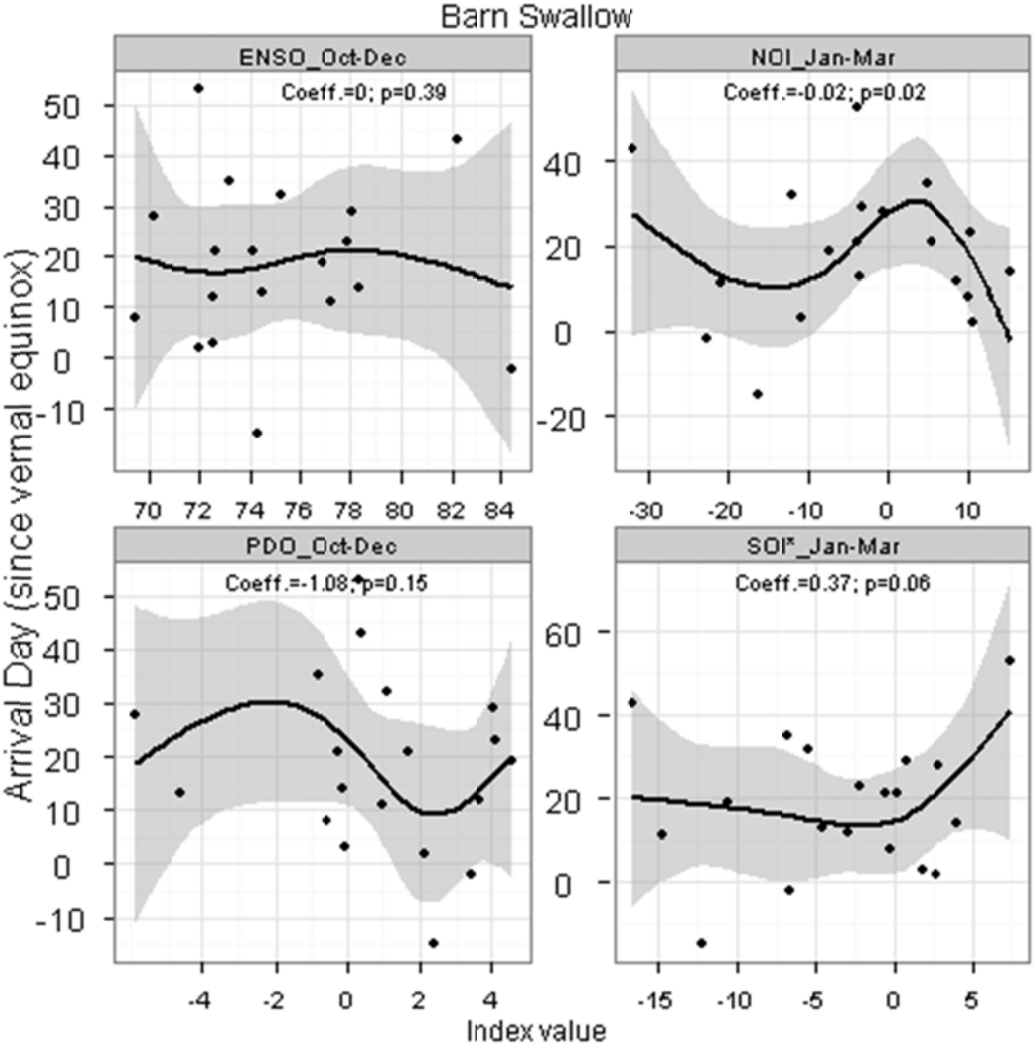


Figure 19. Relationship between day of first arrival and best model fit variable values from four large-scale climate indices (see *Climatic covariates and analysis methods* above, and Appendix, for more details). Results for Barn Swallow. Solid line is the cubic spline smoother regression; shaded areas are the standard errors of the regression.

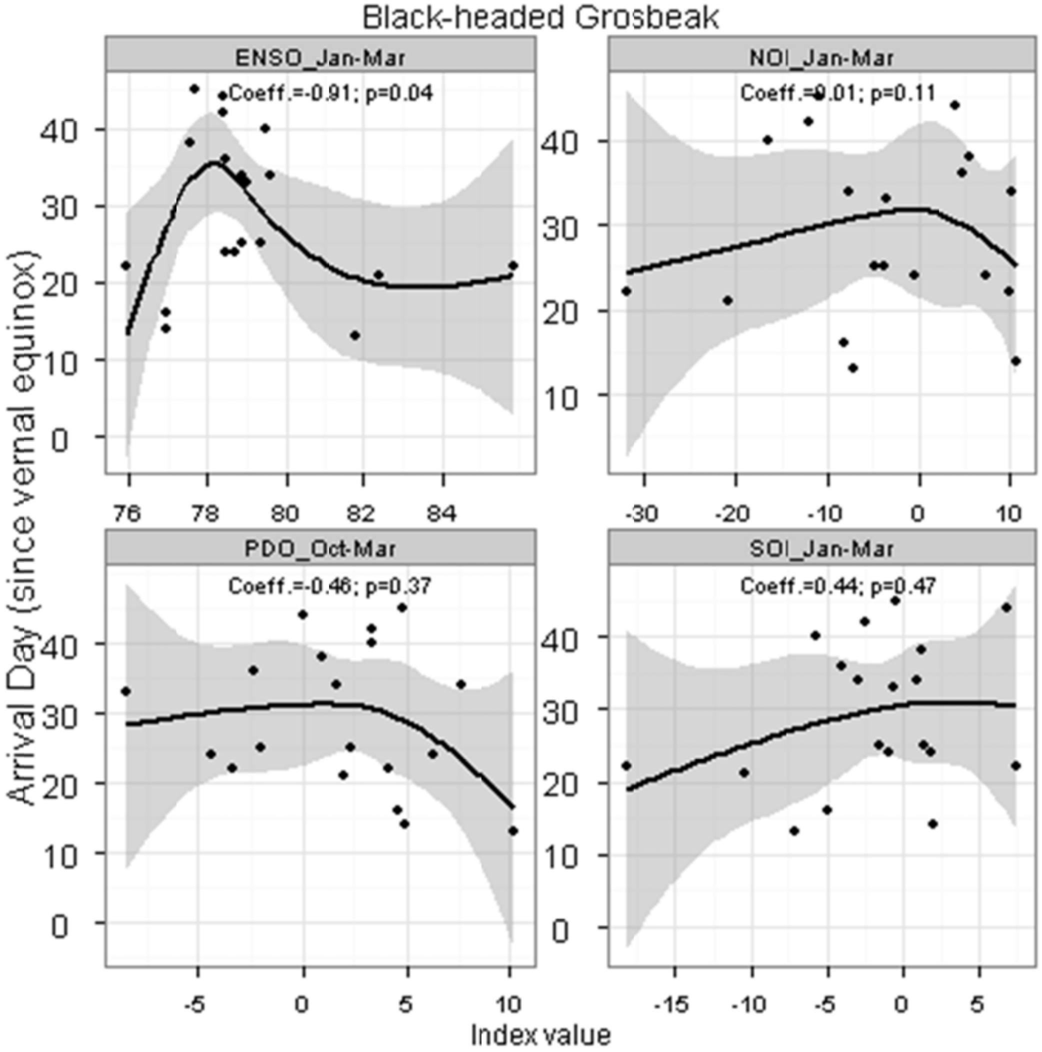


Figure 20. Relationship between day of first arrival and best model fit variable values from four large-scale climate indices (see *Climatic covariates and analysis methods* above, and Appendix, for more details). Results for Black-headed Grosbeak. Solid line is the cubic spline smoother regression; shaded areas are the standard errors of the regression.

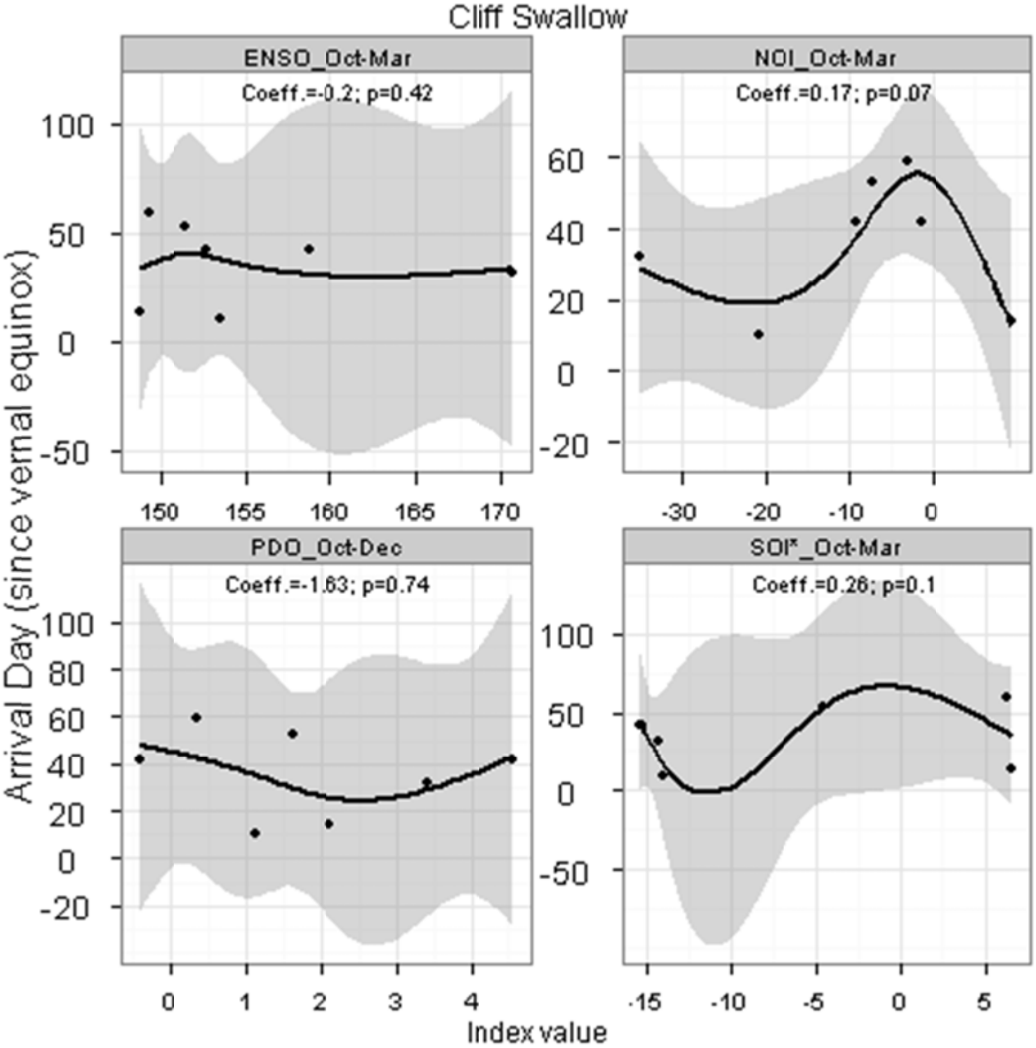


Figure 21. Relationship between day of first arrival and best model fit variable values from four large-scale climate indices (see *Climatic covariates and analysis methods* above, and Appendix, for more details). Results for Cliff Swallow. Solid line is the cubic spline smoother regression; shaded areas are the standard errors of the regression.

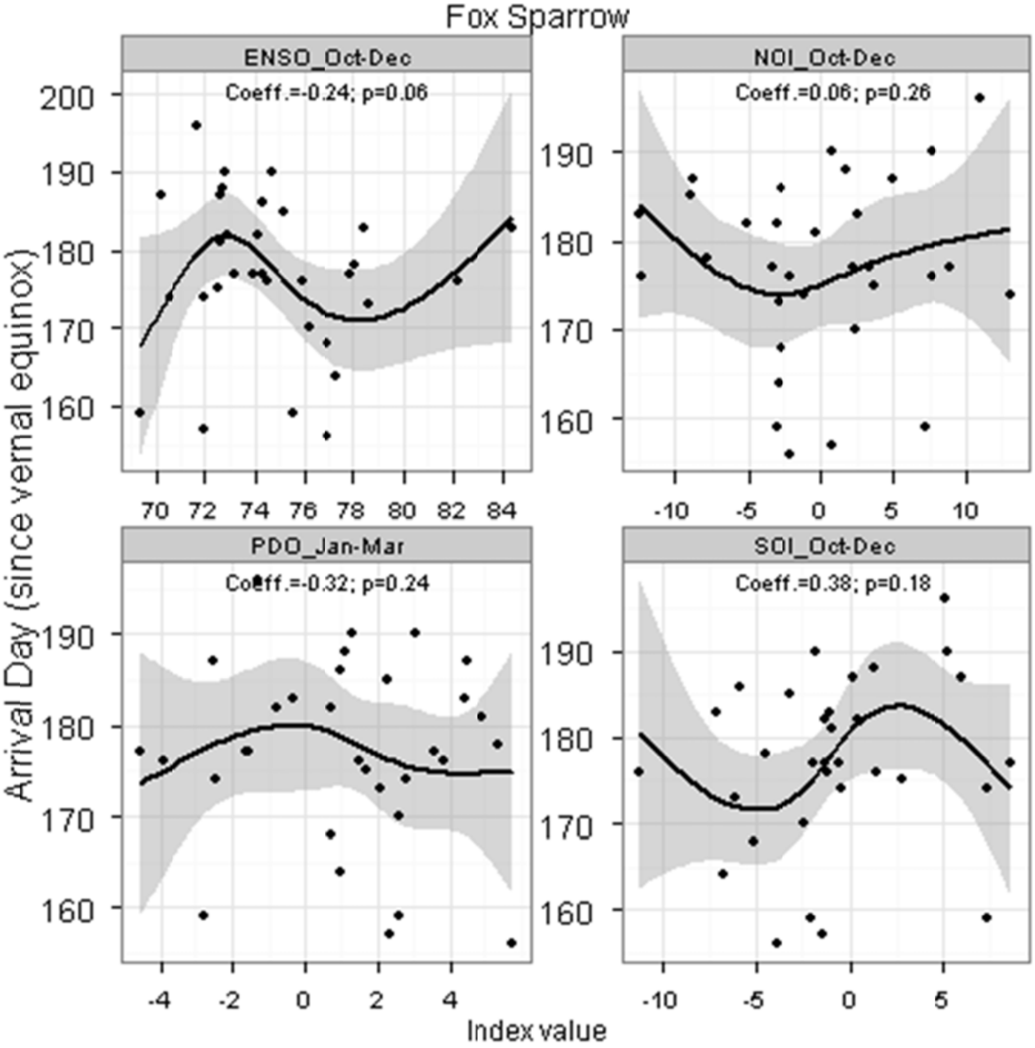


Figure 22. Relationship between day of first arrival and best model fit variable values from four large-scale climate indices (see *Climatic covariates and analysis methods* above, and Appendix, for more details). Results for Fox Sparrow. Solid line is the cubic spline smoother regression; shaded areas are the standard errors of the regression.

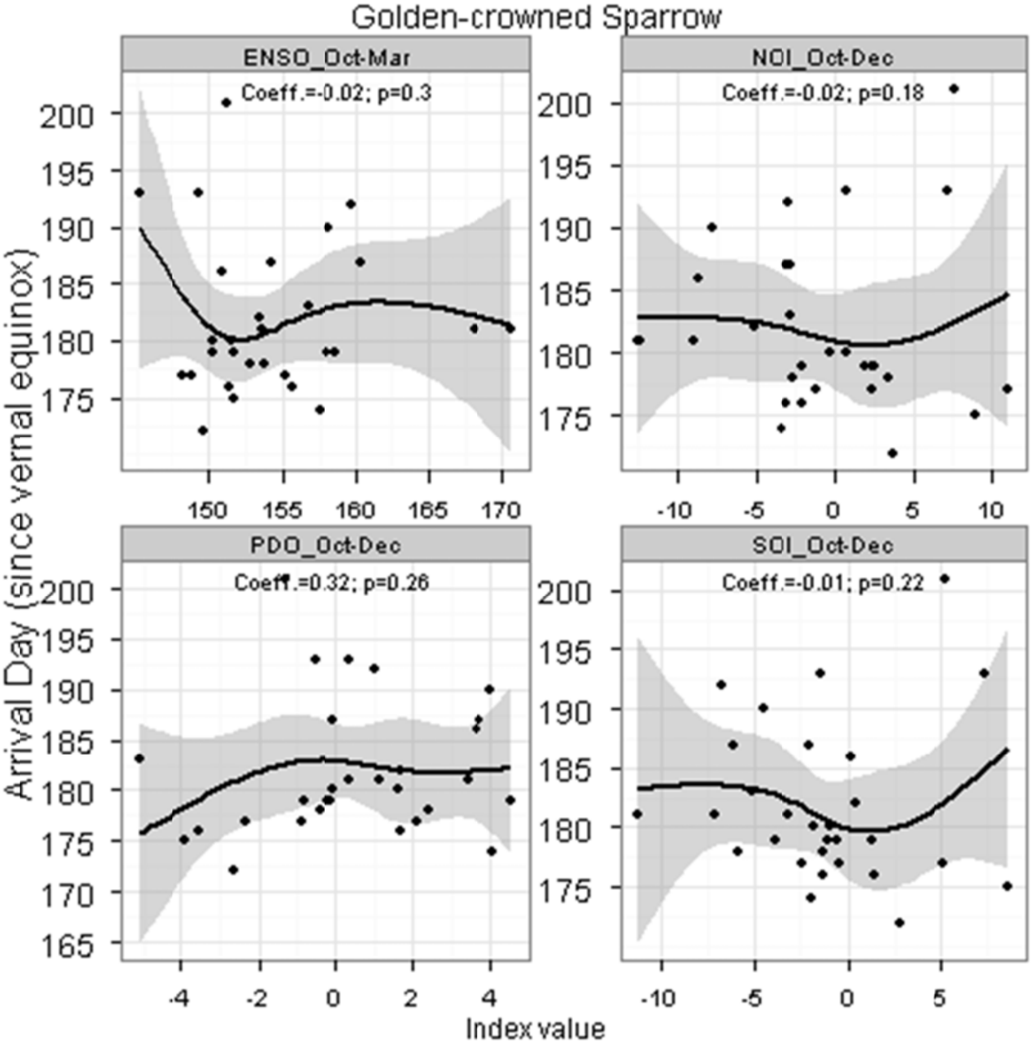


Figure 23. Relationship between day of first arrival and best model fit variable values from four large-scale climate indices (see *Climatic covariates and analysis methods* above, and Appendix, for more details). Results for Golden-crowned Sparrow. Solid line is the cubic spline smoother regression; shaded areas are the standard errors of the regression.

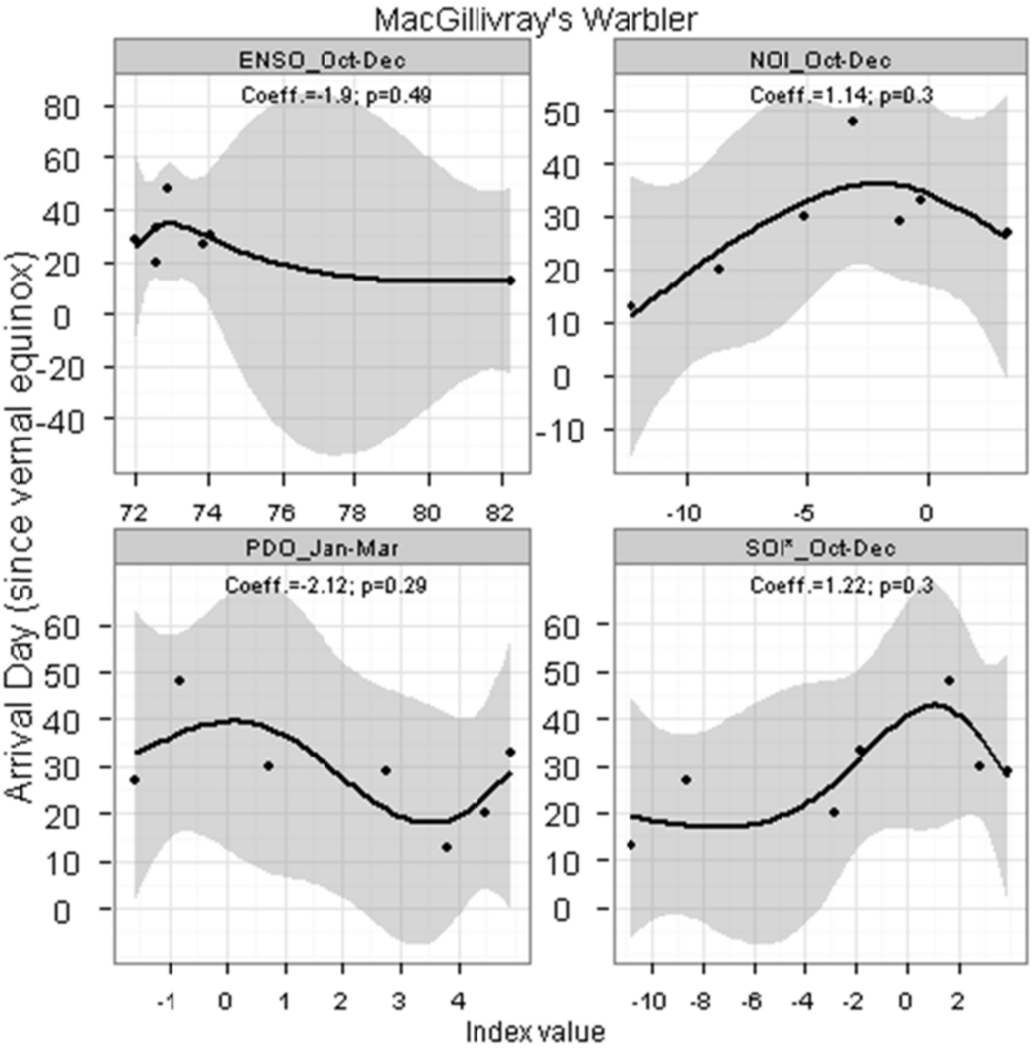


Figure 24. Relationship between day of first arrival and best model fit variable values from four large-scale climate indices (see *Climatic covariates and analysis methods* above, and Appendix, for more details). Results for MacGillivray's Warbler. Solid line is the cubic spline smoother regression; shaded areas are the standard errors of the regression.

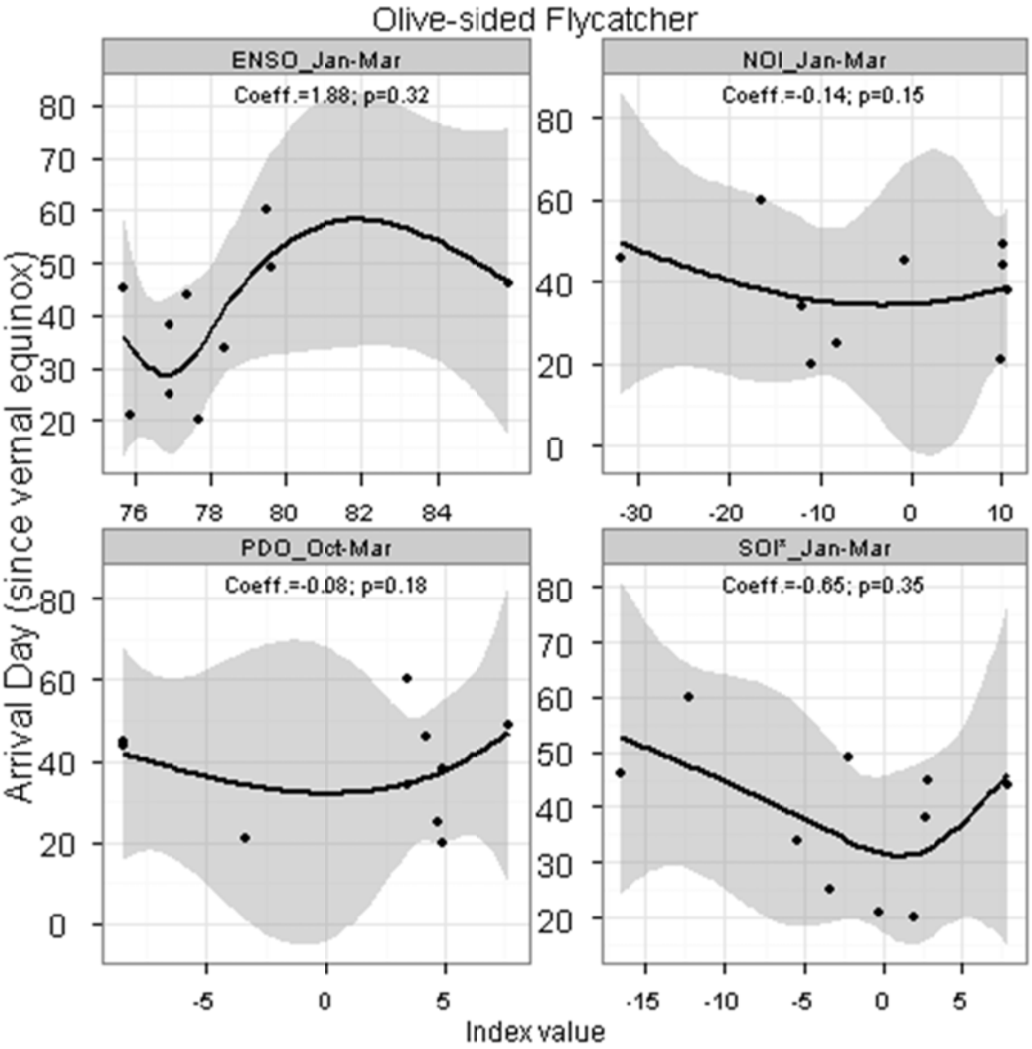


Figure 25. Relationship between day of first arrival and best model fit variable values from four large-scale climate indices (see *Climatic covariates and analysis methods* above, and Appendix, for more details). Results for Olive-sided Flycatcher. Solid line is the cubic spline smoother regression**;** shaded areas are the standard errors of the regression.

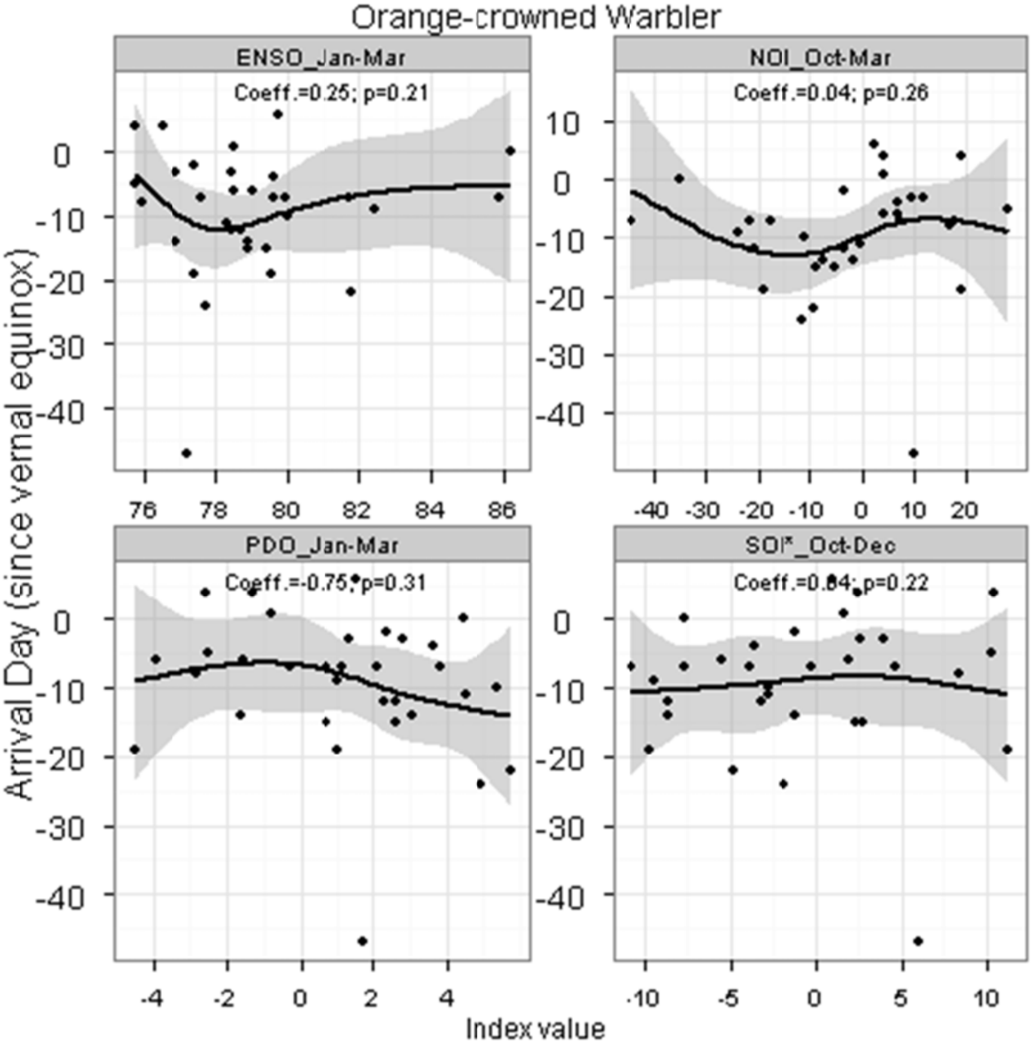


Figure 26. Relationship between day of first arrival and best model fit variable values from four large-scale climate indices (see *Climatic covariates and analysis methods* above, and Appendix, for more details). Results for Orange-crowned Warbler. Solid line is the cubic spline smoother regression; shaded areas are the standard errors of the regression.

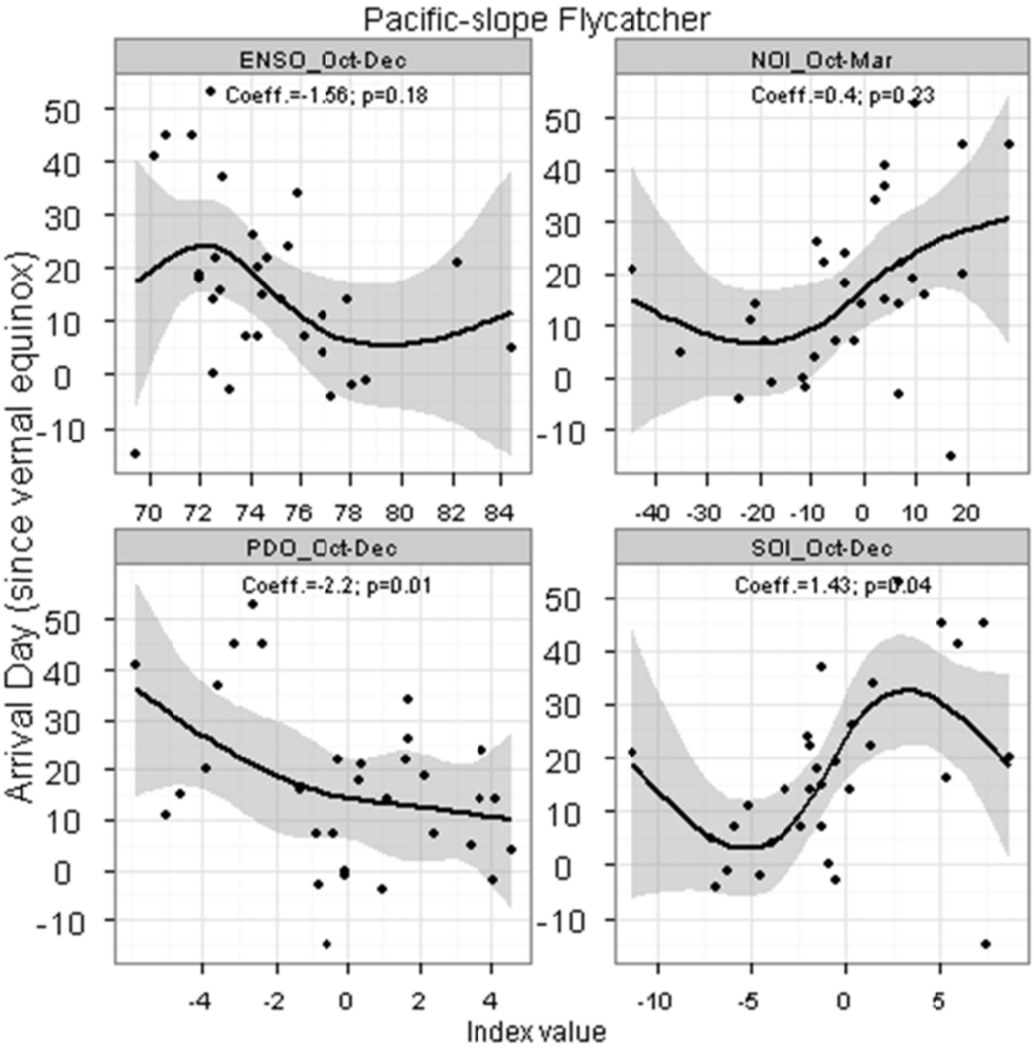


Figure 27. Relationship between day of first arrival and best model fit variable values from four large-scale climate indices (see *Climatic covariates and analysis methods* above, and Appendix, for more details). Results for Pacific-slope Flycatcher. Solid line is the cubic spline smoother regression**;** shaded areas are the standard errors of the regression.

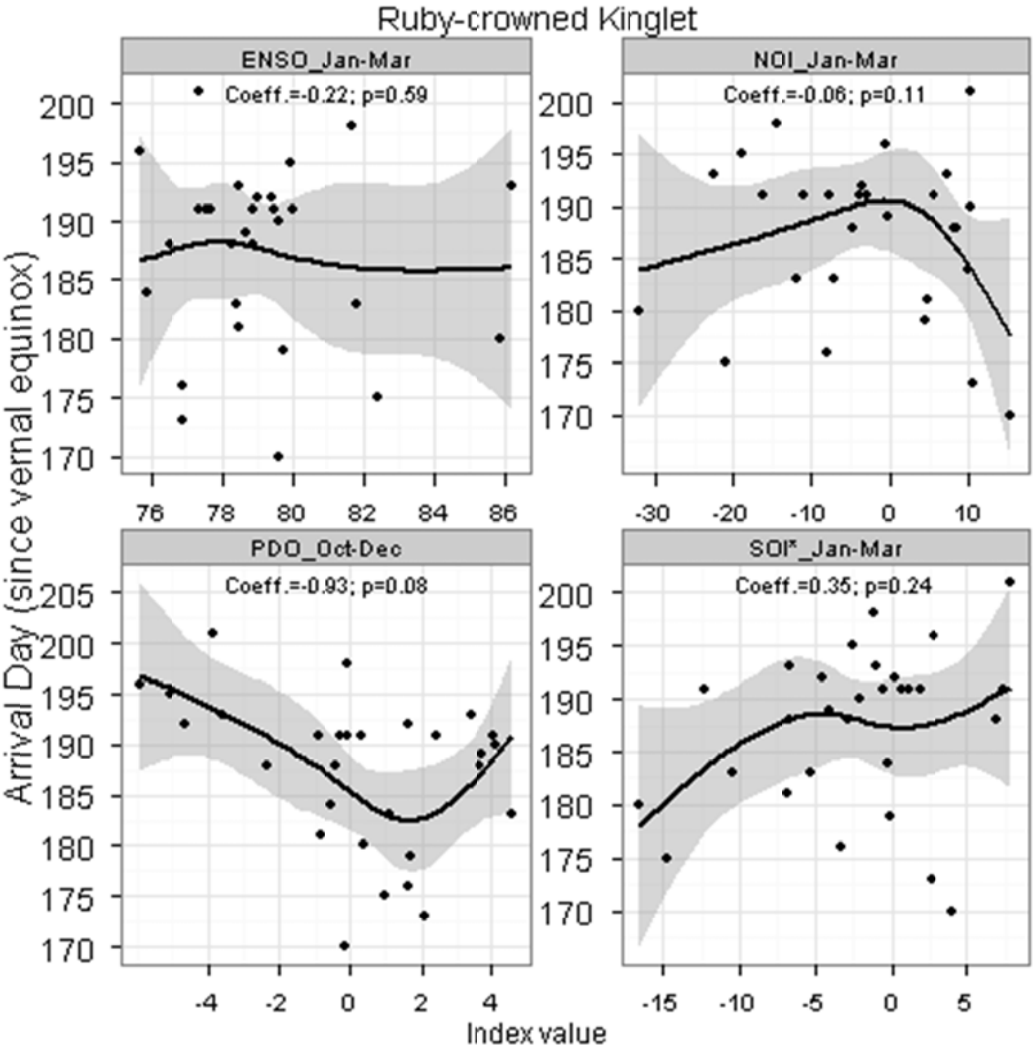


Figure 28. Relationship between day of first arrival and best model fit variable values from four large-scale climate indices (see *Climatic covariates and analysis methods* above, and Appendix, for more details). Results for Ruby-crowned Kinglet. Solid line is the cubic spline smoother regression; shaded areas are the standard errors of the regression.

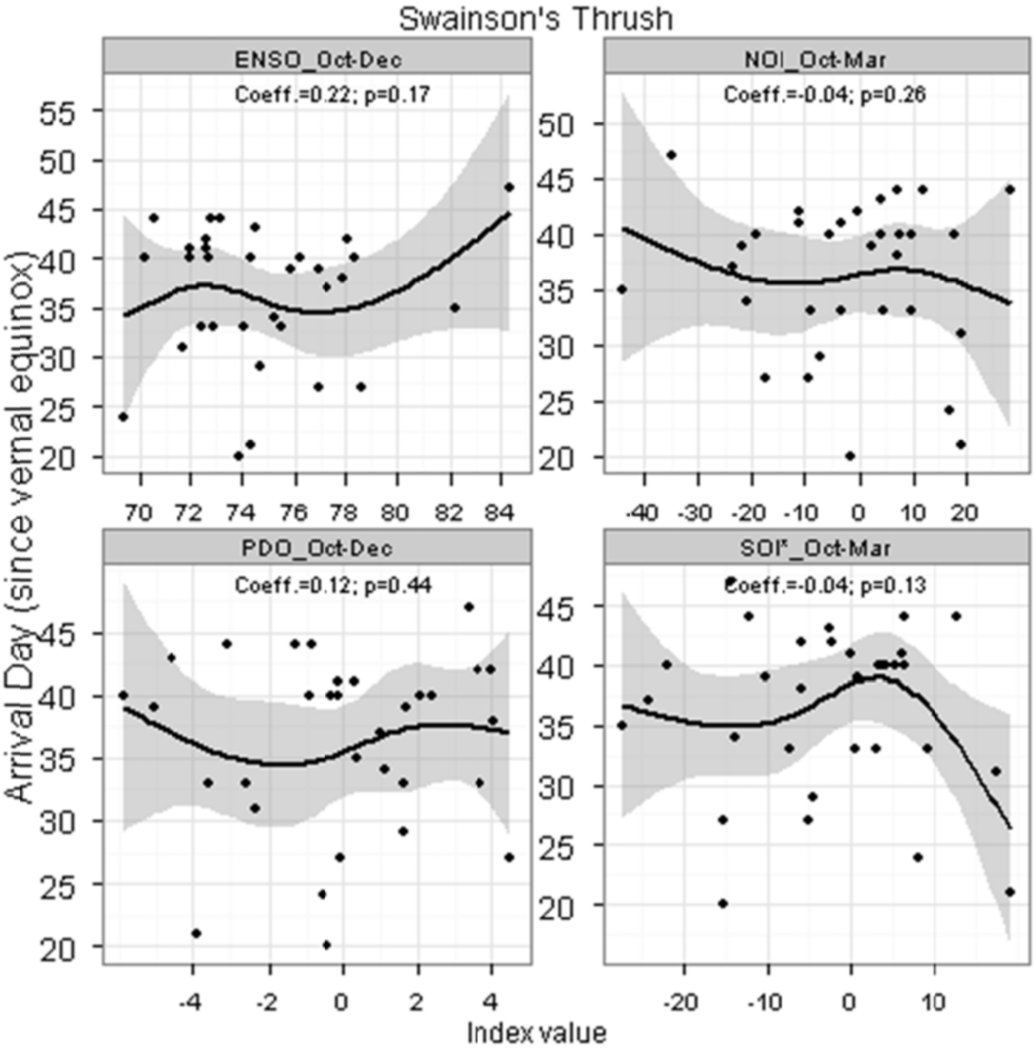


Figure 29. Relationship between day of first arrival and best model fit variable values from four large-scale climate indices (see *Climatic covariates and analysis methods* above, and Appendix, for more details). Results for Swainson's Thrush. Solid line is the cubic spline smoother regression; shaded areas are the standard errors of the regression.

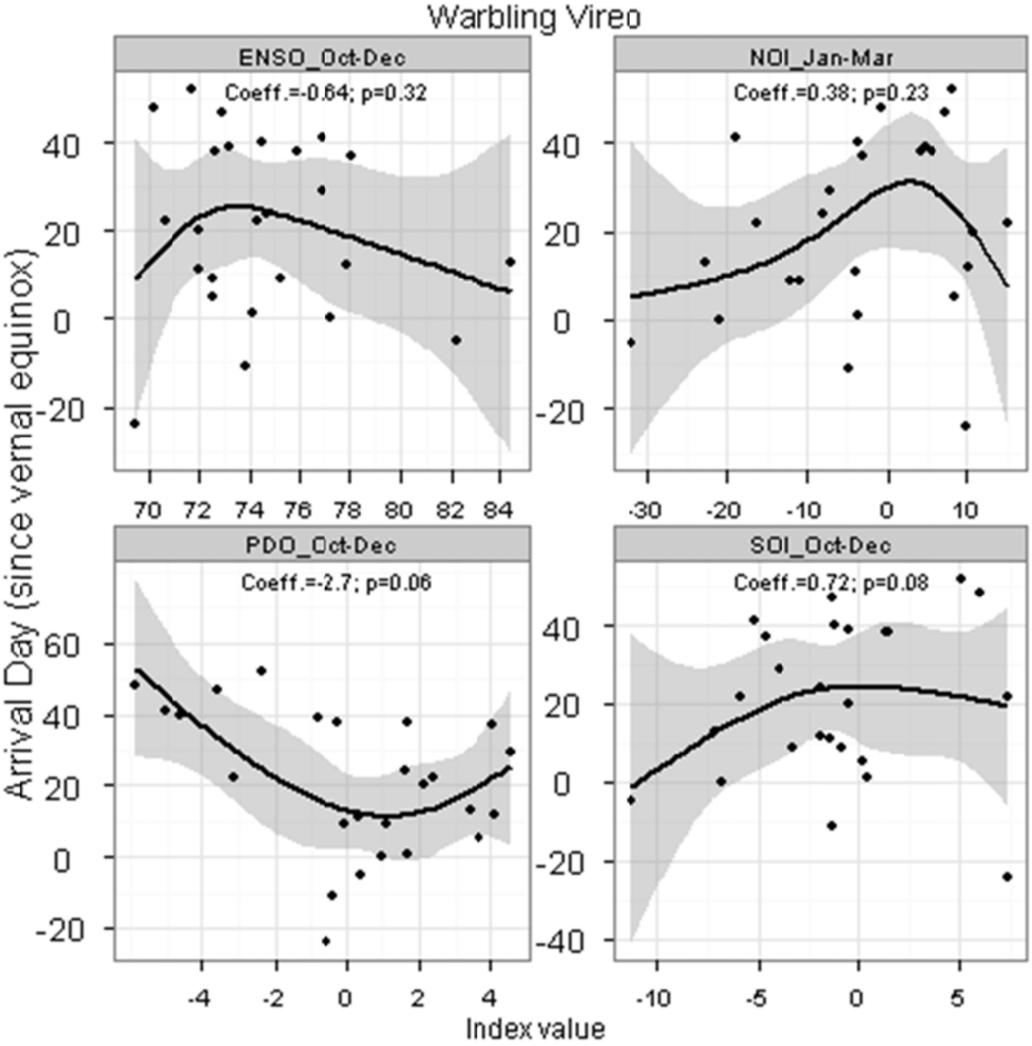


Figure 30. Relationship between day of first arrival and best model fit variable values from four large-scale climate indices (see *Climatic covariates and analysis methods* above, and Appendix, for more details). Results for Warbling Vireo. Solid line is the cubic spline smoother regression; shaded areas are the standard errors of the regression.

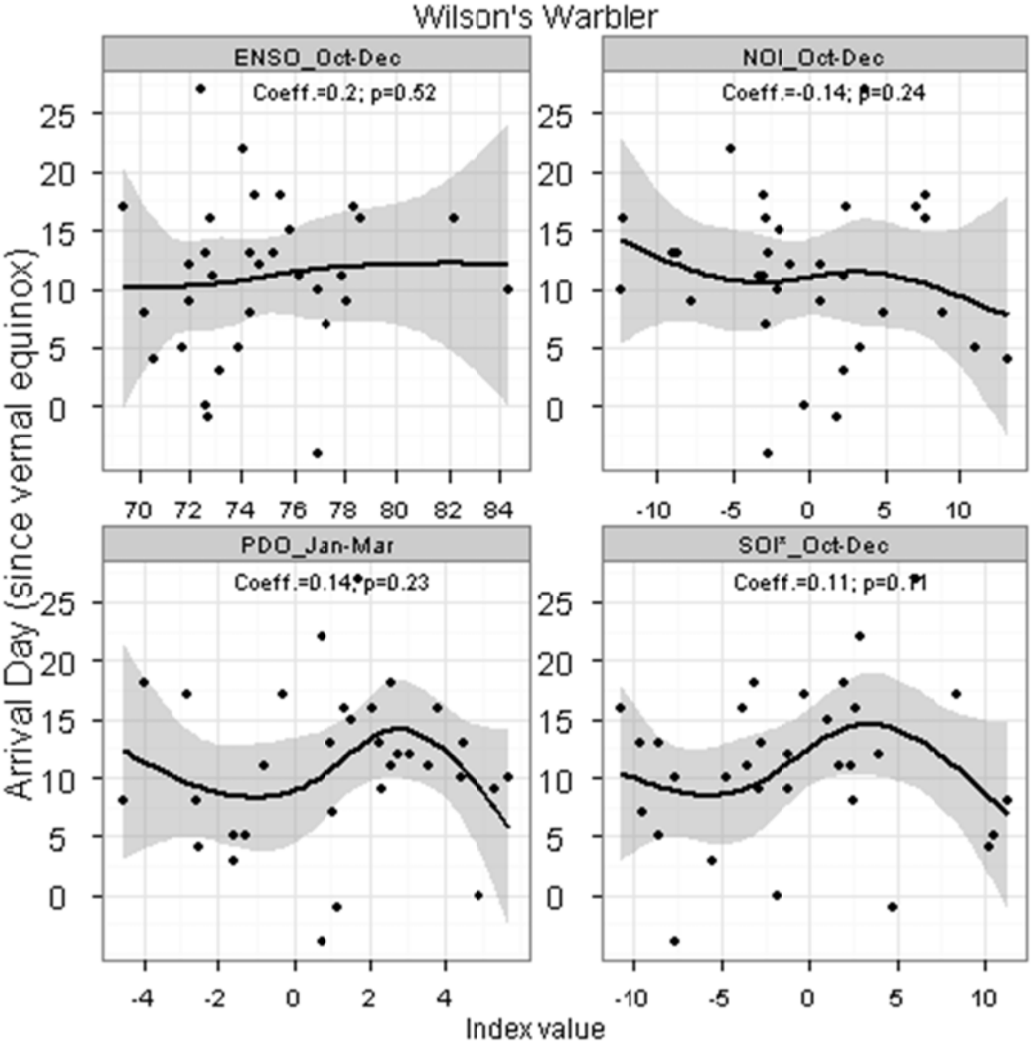


Figure 31. Relationship between day of first arrival and best model fit variable values from four large-scale climate indices (see *Climatic covariates and analysis methods* above, and Appendix, for more details). Results for Wilson's Warbler. Solid line is the cubic spline smoother regression; shaded areas are the standard errors of the regression.

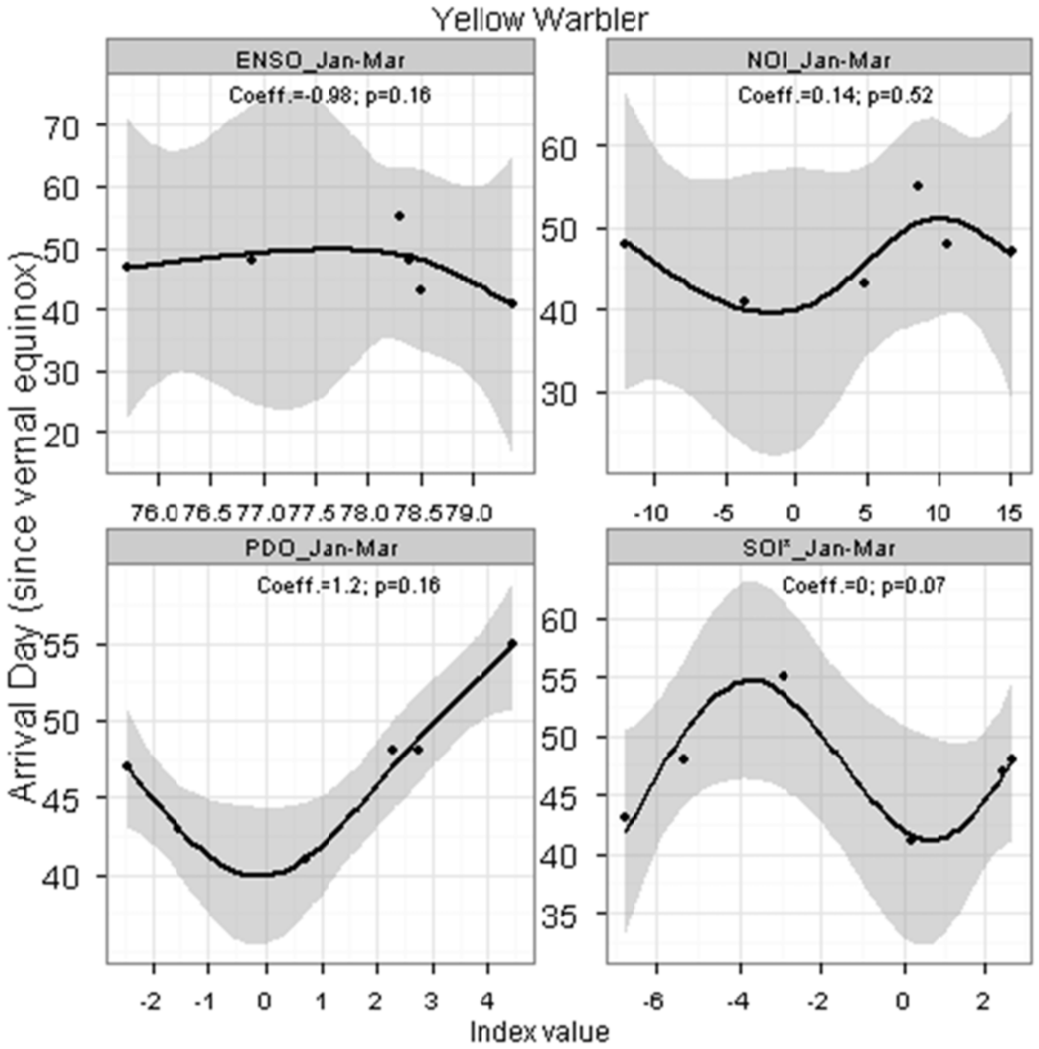


Figure 32. Relationship between day of first arrival and best model fit variable values from four large-scale climate indices (see *Climatic covariates and analysis methods* above, and Appendix, for more details). Results for Yellow Warbler. Solid line is the cubic spline smoother regression; shaded areas are the standard errors of the regression.

Climate Projections

Waterfowl Results

By 2070, climate models project overall mean temperatures in the Central Valley to increase anywhere from 3.1° – 4.3°F, and precipitation, although with much less certainty than predictions for temperature, are expected to decrease by 1.9 – 6.9 inches (Snyder and Sloan 2005, PRBO Conservation Science 2011). Summer temperature spikes (heat waves) are likely to become more common (PRBO Conservation Science 2011). Even under the most optimistic set of changes suggested by these scenarios, in only 50 years, the effects we can predict to observe in breeding waterfowl are significant. Below we present several projections for waterfowl breeding parameters. In these cases, future projections of breeding parameters are model-averaged predictions of 1000 simulations, based on AIC_c weights of complete model set. Future climate variables are estimated from climate scenarios based on a regional climate model (RegCM3; Pal et al. 2007) as summarized in PRBO Conservation Science (2011). Given the high uncertainty in future precipitation models as well as difficulty in determining when the precipitation will occur, we only discuss results based on future temperatures.

Effects of Increased Temperature on Waterfowl Clutch Size

Assuming temperature trends will be consistent within all seasons, our models suggest that for both Mallard and Gadwall, clutch sizes may decrease, especially for waterfowl nesting at Grizzly Island Wildlife Area (**Figure 33**). Mean clutch size for Mallard nesting at Grizzly Island Wildlife Area is projected to decrease by approximately 0.5 eggs, or 6%. For Gadwall, our models for Grizzly Island Wildlife Area suggest that we will observe a decrease in mean clutch size for Gadwall from 9.8 to 9.0-9.2 eggs, representing a decrease in overall productivity of nearly 10%.

Relationship between clutch size and temperature is not as certain at Conaway Ranch. Although our models for clutch size of Gadwall at Conaway Ranch showed a substantial negative relationship with late spring temperatures (**Figure 2**), this was balanced by similar positive relationship with summer and early spring temperatures. Final projections for Gadwall clutch size (assuming comparable temperature increases in all seasons) suggest clutch size may increase in the future for this later-nesting duck species. However, clutch size models for Gadwall nesting at Conaway Ranch, are based on a total of only 138 nests over 10 years. Clutch size for Mallard nesting at Conaway Ranch, are not expected to change much at all.

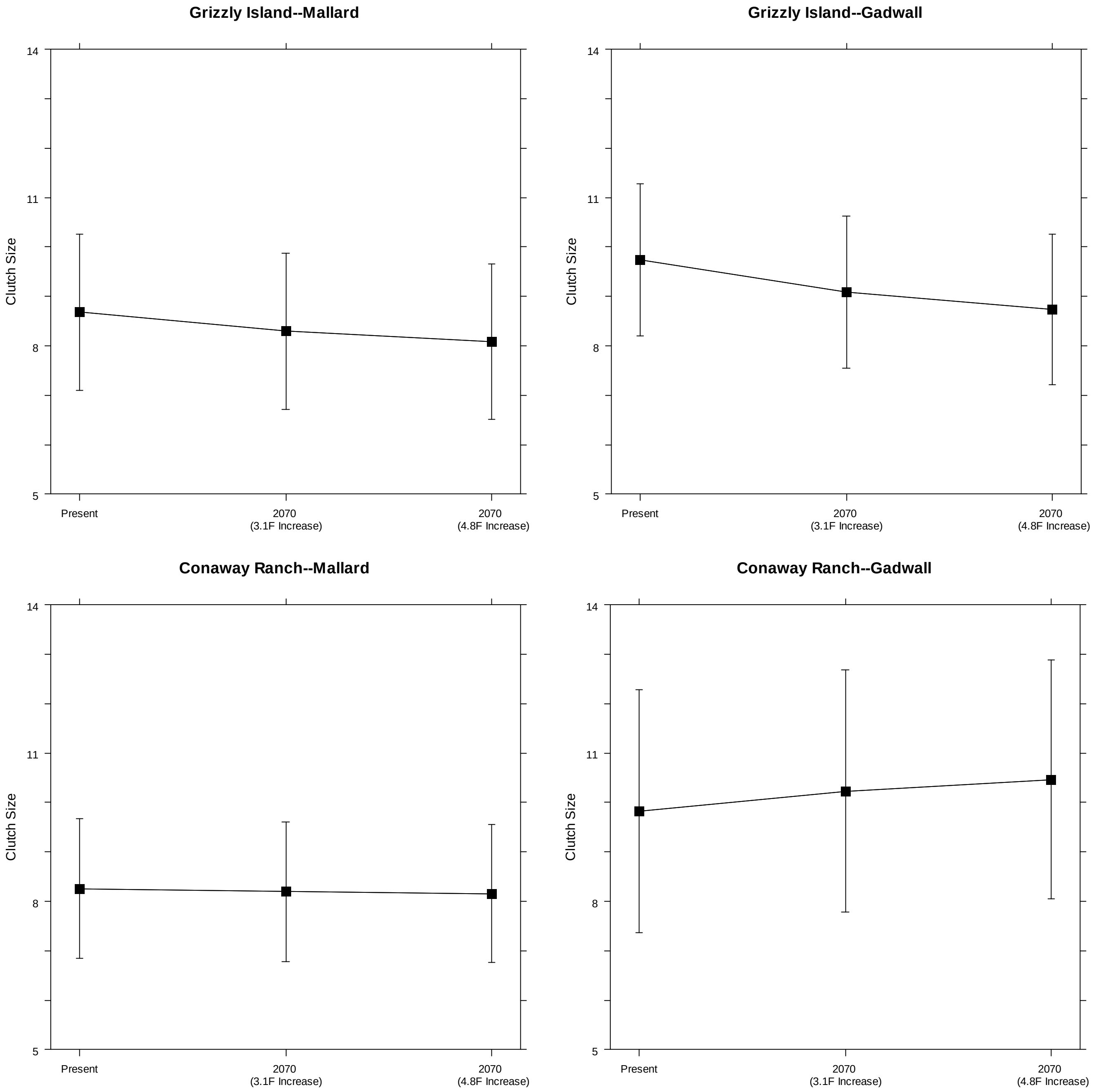


Figure 33. Projected changes in clutch size by 2070 for Mallard and Gadwall nesting at Grizzly Island Wildlife Area and Conaway Ranch. Current data are from Mallard and Gadwall nesting in Grizzly Island Wildlife Area (1985-2010) and Conaway Ranch (1991-2006). Future projections are model-averaged predictions of 1000 simulations, based on AIC_c weights of complete model set. Future climate variables are estimated from climate scenarios based on a regional climate model (RegCM3; Pal et al. 2007) as summarized in PRBO Conservation Science (2011).

Effects of Increased Temperature on Waterfowl Nesting Season Length

The length of the nesting season is a primary component in overall fecundity in nesting ducks. Nest success, in general, is relatively low and a longer nesting season provides more opportunities for waterfowl to renest. Dabbling ducks are known to renest several times in a season if they lose their initial nesting attempts to predators. Conversely, a shorter nesting season can dramatically reduce productivity if seasons become so short as to preclude additional re-nesting attempts. Our projections vary significantly among regions (**Figure 34**), most likely a function of the fact that Grizzly Island Wildlife Area nesting season length may be stabilized by the proximate location of the site to the San Francisco Bay. Instead, Conaway Ranch as a habitat responds more directly to short-term and seasonal weather conditions. Looking more closely at Conaway Ranch where change in the nesting season is projected to be more dramatic, suggests that the majority of change in the nesting season for Mallard will be a result of a season that ends sooner than it currently does. In contrast, Gadwall appear to benefit slightly from the warmer temperatures by nesting slightly earlier in the season (**Figure 35**).

Effects of Increased Temperature on Waterfowl Proportion of Eggs Hatched (Hatching Success)

As temperatures are expected to rise 3-4^{o}F over the next 50+ years, our models project that the hatching success of both species at each site will decline (**Figure 36**). This result is especially pronounced at Conaway Ranch, and presumably within the entire Central Valley where temperatures can become extremely high within the cooling and stabilizing properties of the San Francisco Bay and Coastal regions, such that Grizzly Island Wildlife Area experiences. Poor hatching success may be manifested as a result of both direct egg mortality due to temperature extremes, but it can also be caused by increased rates of abandonment and increased nest recesses by females which would expose eggs to predation.

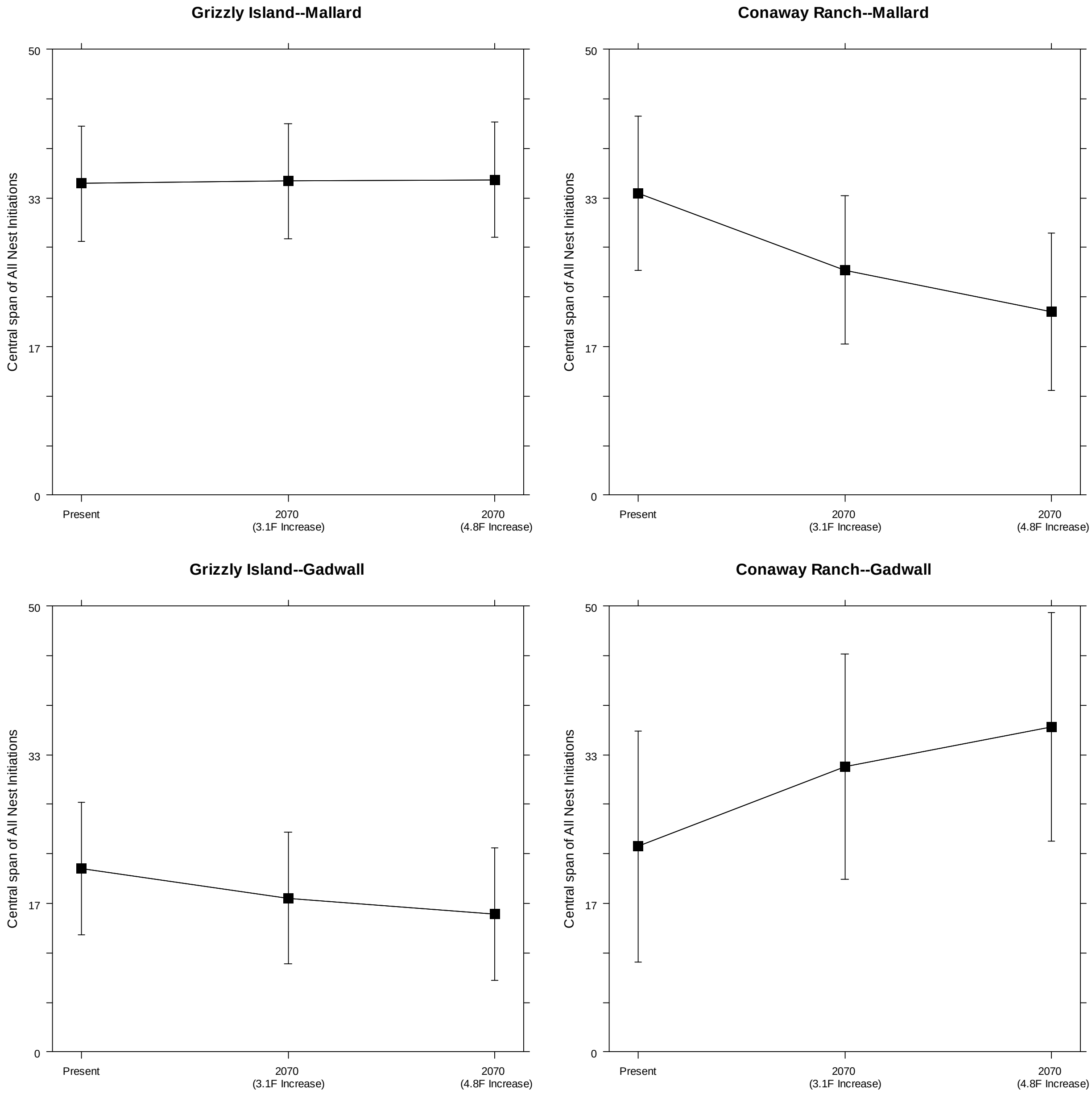


Figure 34. Projected changes in length of nesting season by 2070 for Mallard and Gadwall nesting in Grizzly Island Wildlife Area and Conaway Ranch. Current data are from Mallard and Gadwall nesting at Grizzly Island Wildlife Area (1985-2010) and Conaway Ranch (1991-2006). Future projections are model-averaged predictions of 1000 simulations, based on AIC_c weights of complete model set. Future climate variables are estimated from climate scenarios based on a regional climate model (RegCM3; Pal et al. 2007) as summarized in PRBO Conservation Science (2011).

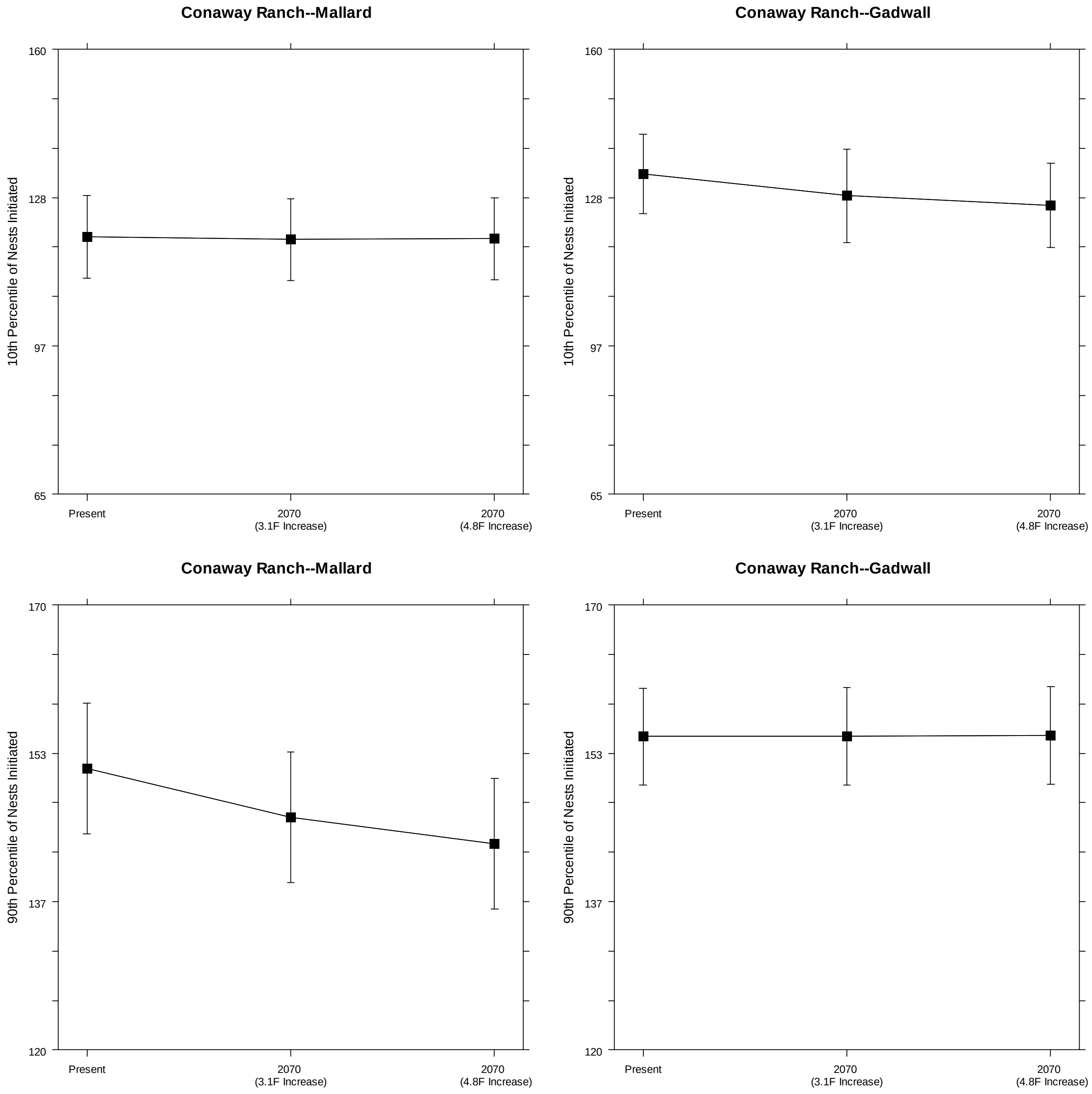


Figure 35. Projected changes in the beginning (top row) and ending (bottom row) of the nesting season by 2070 for Mallard and Gadwall nesting at Grizzly Island Wildlife Area and Conaway Ranch. Current data are from Mallard and Gadwall nesting in Grizzly Island Wildlife Area (1985-2010) and Conaway Ranch (1991-2006). Future projections are model-averaged predictions of 1000 simulations, based on AIC$_c$ weights of complete model set. Future climate variables are estimated from climate scenarios based on a regional climate model (RegCM3; Pal et al. 2007) as summarized in PRBO Conservation Science (2011).

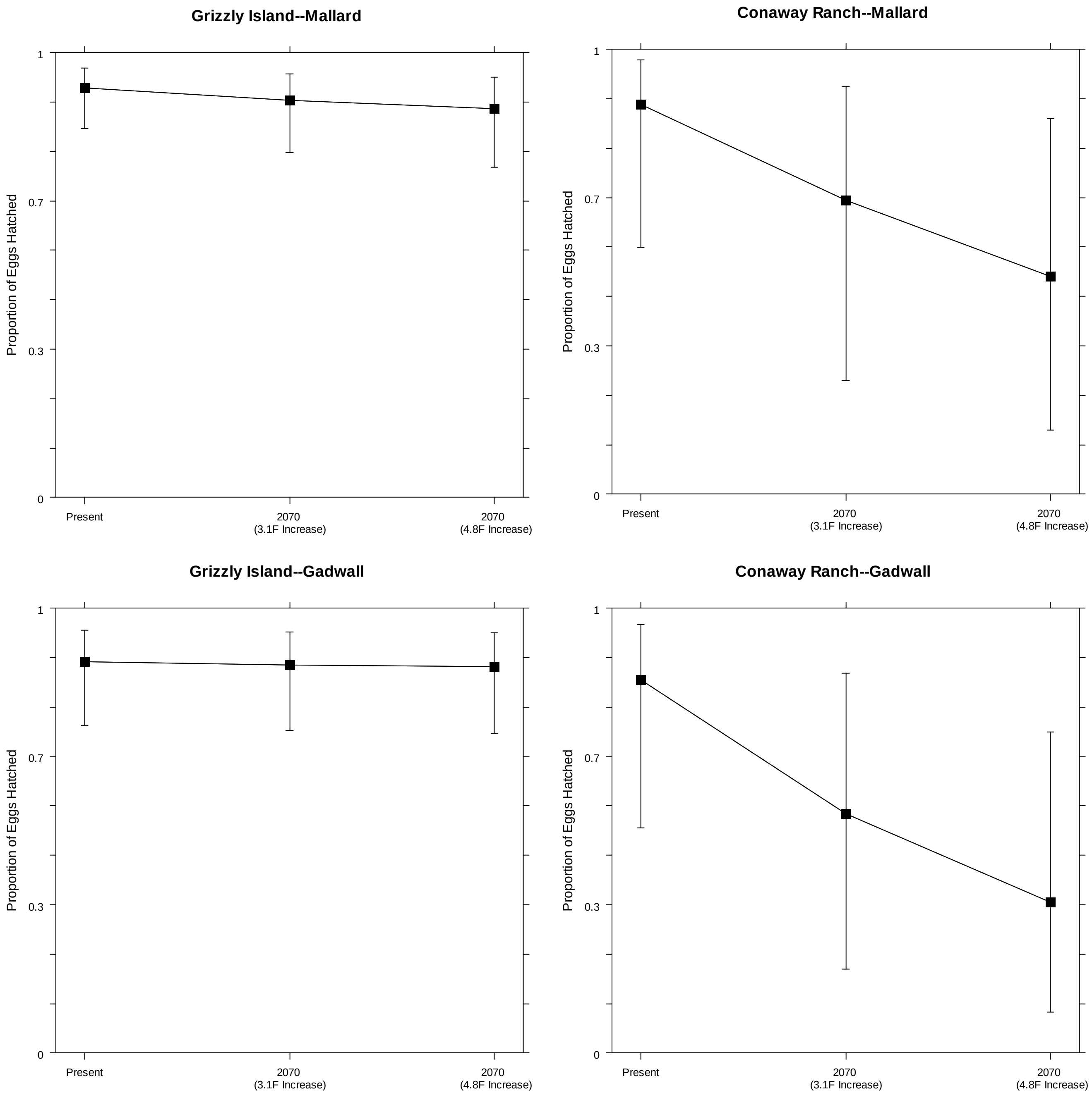


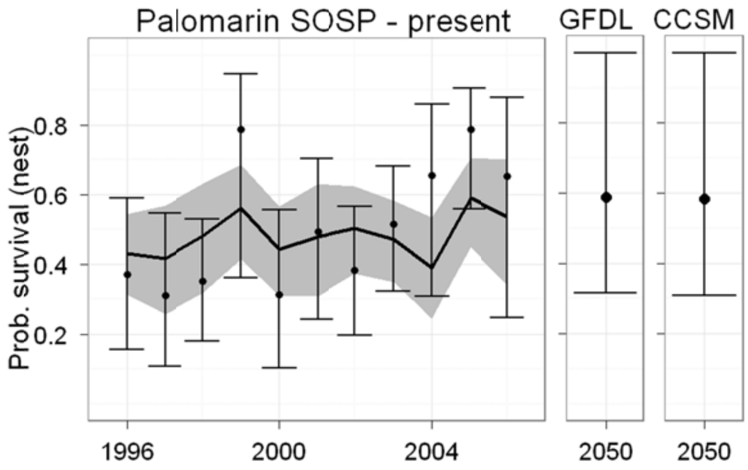
Figure 36. Projected changes in proportion of eggs hatching from a successful nest (hatching rate) by 2070 for Mallard and Gadwall nesting in Grizzly Island Wildlife Area and Conaway Ranch. Current data are from Mallard and Gadwall nesting at Grizzly Island Wildlife Area (1985-2010) and Conaway Ranch (1991-2006). Future projections are model-averaged predictions of 1000 simulations, based on AIC_c weights of complete model set. Future climate variables are estimated from climate scenarios based on a regional climate model (RegCM3; Pal et al. 2007) as summarized in PRBO Conservation Science (2011).

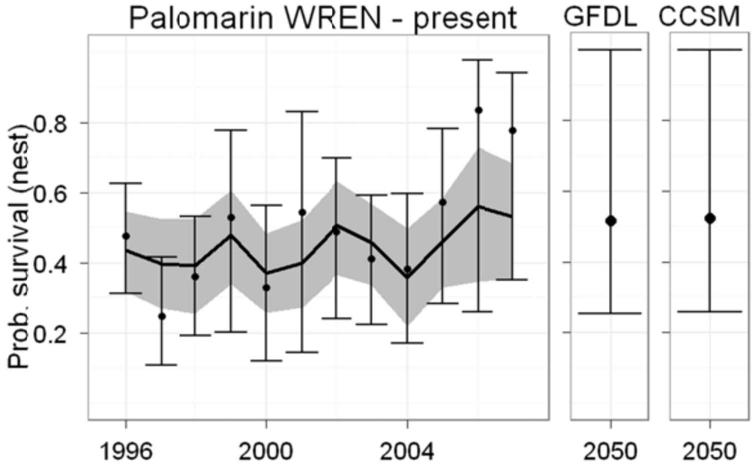
Songbird Results

Effects of Increased Temperature on Songbird Nest Survival

Future projections for the Song Sparrow and Wrentit suggest slightly enhanced nest survival. In particular, the two projections we considered predict higher precipitation and higher seasonality. This translates to more precipitation during the winter months and reduced precipitation during the nesting months. Thus, any negative effects of hatch month precipitation (especially important for tidal marsh Song Sparrow) may lessen in the future. Similarly, more winter rains and warmer winter months may mean more vegetation growth, increasing vegetation cover and productivity (especially important for the Palomarin Wrentit population and the tidal marsh Song Sparrow).

The higher seasonality of the future climate models may translate into fewer hatch-month rains and fewer floods, resulting in higher survival. Sea level rise may cause higher competition for higher nesting grounds, and higher chances of flooding for lower elevation sites (from high tides or from little rainfall). Thus, the projected increase in survival may be inaccurate.


Palomarin SOSP - present
GFDL
CCSM
Prob. survival (nest)
0.2
0.4
0.6
0.8
1996
2000
2004
2050
2050


Palomarin WREN - present
GFDL
CCSM
Prob. survival (nest)
0.2
0.4
0.6
0.8
1996
2000
2004
2050
2050

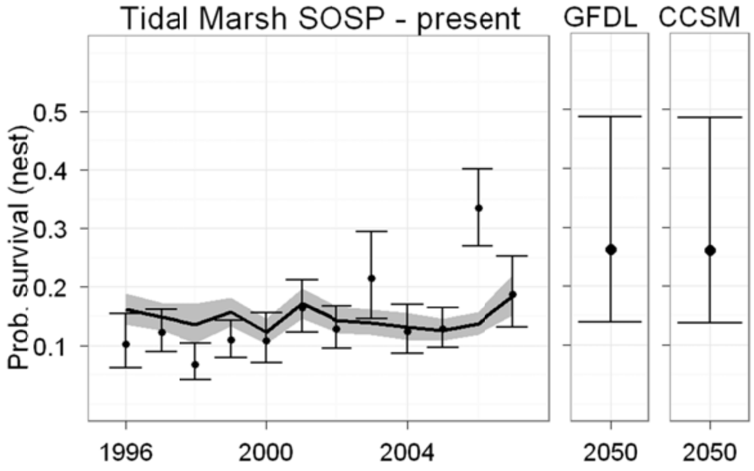

Tidal Marsh SOSP - present
GFDL
CCSM
Prob. survival (nest)
0.1
0.2
0.3
0.4
0.5
1996
2000
2004
2050
2050

Figure 37. Projected nest survival probabilities for Song Sparrows and Wrentits at the Palomarin Research Station and Song Sparrows in tidal marshes of the North Bay under climate scenario A2 of the IPCC as simulated by two different global circulation models.

Management Implications

Waterfowl Nesting Demographics

The habitats in San Francisco Bay-Delta (represented by Grizzly Island Wildlife Area) and the Central Valley (represented by Conaway Ranch) are quite different, and it is not surprising that waterfowl nesting demographics at these sites also are different. Waterfowl nesting within the Grizzly Island Wildlife Area experience environmental conditions that are moderated by the San Francisco Bay and proximity to the coast. There are substantial amounts of available water in the area due to tidal sloughs and related wetlands. On the other hand, Conaway Ranch presents nesting waterfowl with harsher environmental conditions, with little moderation of temperatures by the bay and dependence on human land use for available water.

We found strong relationships between indices of successful nesting and temperature for both Mallard and Gadwall at all sites. However, we expect that conditions in the future will become more extreme in the Central Valley, as the area is projected to increase in temperature and the frequency of extreme heat waves. Although there is no obvious way to directly reduce ambient temperature, managers may have the ability to mitigate the effects that temperature has on waterfowl nests. Our results suggest that, in addition to providing substantial amount of quality nesting habitat, management efforts should aim to create habitat that minimizes temperature that nests are exposed to. For example, nesting areas could contain significant amounts of dense nesting cover that allow waterfowl to select nesting habitat that maximizes the potential for shading, especially later in the nesting season. Management could include using vegetation mixes that leave tall residual vegetation from prior nesting seasons while vegetation grows during the current nesting season. This will be important in both the Central Valley and San Francisco Bay-Delta habitats, but we expect management actions to reduce heat stress to be most effective in the Central Valley.

There is more uncertainty about future precipitation values, compared to future temperature predictions. Nesting habitat in the Central Valley depends largely on spring rains and land use practices (such as rice flooding) for available wetlands. It will be important for managers to continue to consider habitat juxtaposition. Predators of duck nests, such as raccoons and skunks, are known to select wetland and slough edges as preferred foraging routes (Greenwood et al. 1999, Lariviere and Messier 2000, Phillips et al. 2004). Therefore, wetlands and sloughs should not be located within upland duck nesting areas. However, nearby wetlands are necessary as foraging areas for incubating females, and become especially important after eggs hatch and females lead precocial ducklings to water within 24 hours of hatching. In general, duckling survival does not decline with the distance they must travel to water, but wetlands should be located within several miles of nesting habitat (Dzus and Clark 1997, Guyn and Clark 1999, Simpson et al. 2007). It should be a priority for managers to increase the availability of both upland nesting habitat and summer wetlands (also known as reverse cycle wetlands) in preferably large blocks of habitat. This will likely represent a significant challenge in the future as land use practices change.

Our future research goals include investigating both the importance of nesting habitat and larger landscape design (wetland adjacency) in more detail (e.g., Ackerman et al. 2009). Research on the specific types of vegetation required (at both large and small scales), as well as an estimate on the minimum threshold of wetland availability for successful breeding are essential. Knowing where these wetlands should be located in relation to upland nesting habitats will be key, as will understanding the small scale habitat structure and vegetation requirements within upland nesting sites. Thus, while waterfowl do show a strong potential to be negatively affected by future climate change scenarios, proactive management actions can be taken to ameliorate some of these effects.

Songbird Nest Survival

Our results show that the relationship between nest survival and climate are complex and poorly understood. The contrasts between Palomarin and tidal marsh Song Sparrow populations sheds some light on potential stressors (temperature, limited adequate nesting vegetation, possible density-dependent mechanisms). The population at Palomarin seems to be regulated by high density of breeders during periods of above-average rainfall, as was the case in our study, and by bioyear precipitation in periods of low rainfall, as may have been the case of the Chase et al. (2005) study. This is a hypothesis that requires further and more detailed studies.

Tidal marsh habitats of the North Bay have been extensively altered (Stralberg et al. 2010). Populations of the subspecies of special concern Samuel's and Suisun Song Sparrows may be showing poor survival probabilities due to lack of appropriate nesting grounds. Spautz et al. (2006) analyzed the abundance of Song Sparrows in the Bay tidal marshes and found that vegetation composition and structure were important determinants. The lack of proper nesting vegetation may cause higher susceptibility of the populations to the negative effects of high temperature and high precipitation during the breeding season. The latter may correlate with loss of nests due to flooding, which is an important cause of brood loss in our study. Management alternatives may include means to reduce nest mortality due to flooding. Spautz et al. (2006) discuss recommendations to enhance habitats for Song Sparrows, including protection of a mosaic of tidal marsh habitats.

Songbird Arrival Phenology and Large-Scale Climate Indices

The relationship between the day of arrival of Neotropical and Nearctic migrants and global climatic variables is unclear. The large-scale climate indices may be interpreted as single-parameter indicators of large-scale climate processes, but the indices do not capture the entirety of the processes they summarize, and the effect of these processes on the biota is far from clear. We were interested in identifying indicators of change in global climate that would act as cues to the timing of departure from wintering or breeding grounds, and arrival at Palomarin.

Our results suggest that for species such as the Barn Swallow will show later arrival dates during El Niño event years, while species such as the Black-headed Grosbeak will arrive earlier. These patterns must be understood better. Species such as the Pacific-slope Flycatcher seem to arrive later during warmer years. The timing of arrival may have important consequences if it is linked to the availability of resources at the breeding grounds. Arrival past the peak of availability of important nesting resources may result in reduced productivity (Both et al. 2006).

Little can be done locally to mitigate the effects of mismatches between timing of arrival and blooming of important nesting resources for local populations. However, knowledge of these potential effects may prompt range-wide and international actions to reduce the negative impacts on the populations. For example, the timing mismatch may vary throughout the range (because of spatial heterogeneity of nesting resources), or other stressors such as predators or sub-optimal nesting habitats may be restored to reduce negative impacts where possible.

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Appendix 1. Definitions and naming conventions for variables used in models.

Variable	Definition
mean.Tmean.late.winter	mean daily mean temperature in late winter
mean.Tmean.early.spring	mean daily mean temperature in early spring
mean.Tmean.late.spring	mean daily mean temperature in late spring
mean.Tmean.early.summer	mean daily mean temperature in early summer
max.Tmax.late.spring	maximum daily maximum temperature in late spring
max.Tmax.early.summer	maximum daily maximum temperature in early summer
sum.Prcp.late.winter	cumulative precipitation in late winter
sum.Prcp.early.spring	cumulative precipitation in early spring
sum.Prcp.late.spring	cumulative precipitation in late spring
sum.Prcp.early.summer	cumulative precipitation in early summer
count.extreme.high.95.Tmax	number of days where the maximum temperature exceeded 95°F within a specific interval of time
mean.Tmean	mean daily mean temperature within a specific interval of time
max.Tmax	maximum daily maximum temperature within a specific interval of time
sum.Prcp.	cumulative precipitation within a specific interval of time
initdate.julian	initiation date of individual nest measured in days since January 1
date	date at mean of interval
nest age	age of nest at middle of interval
age when nest was found	estimated age of nest when it was first discovered
relative initiation date	initiation date of nest, relative to the 10th percentile of all nests in a given year (initiation date - 10th-percentile.initationdate)
year	year of study
site	nesting field

Appendix 2. Summary of model candidate sets[*]*.*

	Analyses performed on Site Level Averages			Analyses performed on Individual Nests			
Covariate	**10th Percentile of Nest Initiation Dates**	**90th Percentile of Nest Initiation Dates**	**Central Span of Breeding Season**	**Clutch Size**	**Initiation Date**	**Proportion of Eggs Hatched**	**Nest Survival**
mean.Tmean.late.winter	-	-	X	-	X	-	-
mean.Tmean.early.spring	X	X	X	X	X	-	-
mean.Tmean.late.spring	X	X	X	X	X	X	-
mean.Tmean.early.summer	-	X	X	X	-	X	-
max.Tmax.late.spring	-	-	-	-	-	X	-
max.Tmax.early.summer	-	-	-	-	-	X	-
sum.Prcp.late.winter	X	X	X	X	X	-	-
sum.Prcp.early.spring	X	X	X	X	X	-	-
sum.Prcp.late.spring	X	X	X	X	X	-	-
sum.Prcp.early.summer	-	X	X	X	-	X	-
count.extreme.high.95.Tmax	-	-	-	-	-	X	X**
mean.Tmean	-	-	-	-	-	-	X**
max.Tmax	-	-	-	-	-	-	X**
sum.Prcp	-	-	-	-	-	-	X**
initiation.date	-	-	-	X	-	-	-
date	-	-	-	-	-	-	X
(date)^2	-	-	-	-	-	-	X
nest age	-	-	-	-	-	-	X
(nest age)^2	-	-	-	-	-	-	X
age when nest was found	-	-	-	-	-	-	X
(age when nest was found)^2	-	-	-	-	-	-	X
relative initation date	-	-	-	-	-	-	X
(relative initiation date)^2	-	-	-	-	-	-	X
year (factor)	Random	Random	Random	Random	Random	Random	X
site (factor)	Random	Random	Random	Random	Random	Random	-

* See Appendix 1 for variable definitions

** including all 2-way interactions among these covariates

Appendix 3. Variables in competing models for songbirds' nest survival analyses.

Variable	Song Sparrow Palomarin	Wrentit Palomarin	Song Sparrow Tidal Marshes
Nest age (at middle of exposure interval)	X*	X*	X*
(Nest age)^2	X*	X*	X*
(Nest age)^3	X*	X*	
Day since first initiation date of the season	X	X	X*
(Day since first initiation date of the season)^2	X	X	X*
(Day since first initiation date of the season)^3	X	X	X*
Year (factor)	X*	X*	X*
Precipitation October-March	X	X	X
Total precipitation on hatch month		X	X*
Total precipitation on prior month	X	X	X*
Total precipitiation on prior 2 months		X	
Total precipitation on prior 3 months		X*	X*
Min. temperature on hatch month		X*	X*
Min. temperature on prior month	X	X	
Min. temperature on prior 2 months	X	X	X*
Min. temperature on prior 3 months	X		
Max. temperature on hatch month	X		X*
Max. temperature on prior month	X	X	
Max. temperature on prior 2 months	X	X	X*
Max. temperature on prior 3 months	X		X*
Number of competing models	14	10	12

Asterisks (*) indicate significant contributions to model fits (p-value < 0.05).

Appendix 4. Model selection tables for waterfowl clutch size, nest initiation date, 10th percentile of nest initiation dates, central span of nests initiated, 90th percentile of nest initiation dates, proportion of eggs hatched, and nest survival.

- All models, except nest survival models included site and year as random effects. See **Appendix 1** for definitions of all variables used in models.
- Only models with AIC_c<=3.0 are provided within these tables. Please refer to **Appendix 2** for a list of all the models run for a given demographic parameter.
- Variable importance is presented for all parameters where variable importance was >= 0.5

Clutch Size

Mallard at Grizzly Island Wildlife Area

Model Selection Table

Model	K	AICc	ΔAICc	Weight
clutchsize ~ mean.Tmean.late.spring + mean.Tmean.early.summer + initdate.julian	6	18953.16	0.00	0.07
clutchsize ~ mean.Tmean.late.spring + initdate.julian	5	18953.86	0.70	0.05
clutchsize ~ mean.Tmean.late.spring + sum.Prcp.early.summer + mean.Tmean.early.summer + initdate.julian	7	18954.36	1.20	0.04
clutchsize ~ sum.Prcp.late.winter + mean.Tmean.late.spring + mean.Tmean.early.summer + initdate.julian	7	18954.85	1.69	0.03
clutchsize ~ mean.Tmean.late.spring + sum.Prcp.early.summer + initdate.julian	6	18954.89	1.73	0.03
clutchsize ~ sum.Prcp.early.spring + mean.Tmean.late.spring + mean.Tmean.early.summer + initdate.julian	7	18955.10	1.94	0.03
clutchsize ~ mean.Tmean.early.spring + mean.Tmean.late.spring + mean.Tmean.early.summer + initdate.julian	7	18955.12	1.96	0.03
clutchsize ~ sum.Prcp.late.spring + mean.Tmean.late.spring + mean.Tmean.early.summer + initdate.julian	7	18955.16	2.00	0.02
clutchsize ~ sum.Prcp.late.winter + mean.Tmean.late.spring + sum.Prcp.early.summer + mean.Tmean.early.summer + initdate.julian	8	18955.42	2.26	0.02
clutchsize ~ sum.Prcp.early.spring + mean.Tmean.late.spring + initdate.julian	6	18955.43	2.27	0.02
clutchsize ~ mean.Tmean.early.summer + initdate.julian	5	18955.46	2.30	0.02
clutchsize ~ mean.Tmean.early.spring + mean.Tmean.late.spring + initdate.julian	6	18955.61	2.45	0.02
clutchsize ~ sum.Prcp.late.winter + mean.Tmean.late.spring + initdate.julian	6	18955.70	2.54	0.02
clutchsize ~ sum.Prcp.late.spring + mean.Tmean.late.spring + initdate.julian	6	18955.82	2.66	0.02
clutchsize ~ sum.Prcp.late.spring + mean.Tmean.early.summer + initdate.julian	6	18955.99	2.83	0.02

Variable Importance

Variable	Variable Importance	Model-averaged Coefficient
initdate.julian	1.000	-0.038
mean.Tmean.late.spring	0.709	-0.049
mean.Tmean.early.summer	0.621	-0.065

Mallard at Conaway Ranch

Model Selection

Model	K	AICc	ΔAICc	Weight
clutchsize ~ sum.Prcp.late.winter + mean.Tmean.early.spring + mean.Tmean.late.spring + sum.Prcp.early.summer + initdate.julian	8	2104.72	0.00	0.11
clutchsize ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + mean.Tmean.late.spring + sum.Prcp.early.summer + initdate.julian	9	2106.41	1.68	0.05
clutchsize ~ mean.Tmean.early.spring + mean.Tmean.late.spring + sum.Prcp.early.summer + initdate.julian	7	2106.74	2.02	0.04
clutchsize ~ sum.Prcp.late.winter + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring + sum.Prcp.early.summer + initdate.julian	9	2106.74	2.02	0.04
clutchsize ~ sum.Prcp.late.winter + mean.Tmean.early.spring + mean.Tmean.late.spring + sum.Prcp.early.summer + mean.Tmean.early.summer + initdate.julian	9	2106.75	2.03	0.04
clutchsize ~ mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring + sum.Prcp.early.summer + initdate.julian	8	2107.51	2.79	0.03

Variable Importance

Variable	Variable Importance	Model-averaged Coefficient
initdate.julian	1.00	-0.03
sum.Prcp.early.summer	0.66	0.44
mean.Tmean.early.spring	0.65	-0.08
sum.Prcp.late.winter	0.62	0.02
mean.Tmean.late.spring	0.61	0.06

Gadwall at Grizzly Island Wildlife Area

Model Selection

Model	K	AICc	ΔAICc	Weight
clutchsize ~ sum.Prcp.early.spring + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring + initdate.julian	8	4929.27	0.00	0.11
clutchsize ~ sum.Prcp.early.spring + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring + sum.Prcp.early.summer + initdate.julian	9	4930.51	1.24	0.06
clutchsize ~ mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring + mean.Tmean.early.summer + initdate.julian	8	4931.02	1.75	0.05
clutchsize ~ sum.Prcp.early.spring + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring + mean.Tmean.early.summer + initdate.julian	9	4931.07	1.80	0.04
clutchsize ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring + initdate.julian	9	4931.12	1.85	0.04
clutchsize ~ mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring + initdate.julian	7	4931.28	2.01	0.04
clutchsize ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring + sum.Prcp.early.summer + initdate.julian	10	4931.93	2.66	0.03
clutchsize ~ sum.Prcp.early.spring + mean.Tmean.early.spring + mean.Tmean.late.spring + initdate.julian	7	4932.16	2.89	0.03
clutchsize ~ mean.Tmean.early.spring + mean.Tmean.late.spring + mean.Tmean.early.summer + initdate.julian	7	4932.25	2.98	0.02
clutchsize ~ sum.Prcp.early.spring + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring + sum.Prcp.early.summer + mean.Tmean.early.summer + initdate.julian	10	4932.27	3.00	0.02
clutchsize ~ mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring + sum.Prcp.early.summer + mean.Tmean.early.summer + initdate.julian	9	4932.27	3.00	0.02

Variable Importance

Variable	**Variable Importance**	**Model-averaged Coefficient**
initdate.julian	1.00	-0.05
mean.Tmean.early.spring	0.86	-0.11
mean.Tmean.late.spring	0.82	-0.07
sum.Prcp.late.spring	0.69	-0.08
sum.Prcp.early.spring	0.58	0.02

Gadwall at Conaway Ranch

Model Selection

Model	K	AICc	ΔAICc	Weight
clutchsize ~ sum.Prcp.early.spring + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring + sum.Prcp.early.summer + mean.Tmean.early.summer + initdate.julian	10	348.32	0.00	0.30
clutchsize ~ mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring + sum.Prcp.early.summer + mean.Tmean.early.summer + initdate.julian	9	348.74	0.42	0.24
clutchsize ~ sum.Prcp.late.winter + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring + sum.Prcp.early.summer + mean.Tmean.early.summer + initdate.julian	10	349.54	1.23	0.16
clutchsize ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring + sum.Prcp.early.summer + mean.Tmean.early.summer + initdate.julian	11	350.33	2.01	0.11

Variable Importance

Variable	Variable Importance	Model-averaged Coefficient
mean.Tmean.late.spring	0.99	-1.12
initdate.julian	0.98	-0.03
mean.Tmean.early.summer	0.94	0.79
sum.Prcp.early.summer	0.90	-3.16
mean.Tmean.early.spring	0.90	0.47

sum.Prcp.late.spring	0.90	-1.20

Nest Initiation Date

Mallard at Grizzly Island Wildlife Area

Model Selection

Model	K	AICc	ΔAICc	Weight
initdate.julian ~ mean.Tmean.late.winter + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring	7	90801.72	0.00	0.22
initdate.julian ~ mean.Tmean.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring	8	90803.58	1.85	0.09
initdate.julian ~ sum.Prcp.late.winter + mean.Tmean.late.winter + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring	8	90803.62	1.90	0.08
initdate.julian ~ mean.Tmean.late.winter + mean.Tmean.early.spring + mean.Tmean.late.spring	6	90803.97	2.25	0.07
initdate.julian ~ mean.Tmean.late.winter + sum.Prcp.late.spring + mean.Tmean.late.spring	6	90804.27	2.55	0.06
initdate.julian ~ mean.Tmean.late.winter + mean.Tmean.late.spring	5	90804.68	2.96	0.05

Variable Importance

Variable	Variable Importance	Model-averaged Coefficient
mean.Tmean.late.spring	0.93	-1.94
mean.Tmean.late.winter	0.84	1.93
mean.Tmean.early.spring	0.67	-1.28
sum.Prcp.late.spring	0.60	-1.41

Mallard at Conaway Ranch

Model Selection

Model	K	AICc	ΔAICc	Weight
initdate.julian ~ sum.Prcp.late.winter + mean.Tmean.late.winter + mean.Tmean.early.spring	6	8223.65	0.00	0.09
initdate.julian ~ sum.Prcp.late.winter + mean.Tmean.late.winter	5	8223.85	0.20	0.08
initdate.julian ~ sum.Prcp.late.winter + mean.Tmean.late.winter + mean.Tmean.early.spring + sum.Prcp.late.spring	7	8224.53	0.88	0.06
initdate.julian ~ sum.Prcp.late.winter + mean.Tmean.late.winter + mean.Tmean.early.spring + mean.Tmean.late.spring	7	8225.14	1.49	0.04
initdate.julian ~ sum.Prcp.late.winter + mean.Tmean.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring	7	8225.32	1.67	0.04
initdate.julian ~ 1	3	8225.47	1.82	0.04
initdate.julian ~ sum.Prcp.late.winter + mean.Tmean.late.winter + mean.Tmean.late.spring	6	8225.79	2.14	0.03
initdate.julian ~ sum.Prcp.late.winter + mean.Tmean.late.winter + sum.Prcp.early.spring	6	8225.85	2.20	0.03
initdate.julian ~ sum.Prcp.late.winter + mean.Tmean.late.winter + sum.Prcp.late.spring	6	8225.86	2.21	0.03
initdate.julian ~ mean.Tmean.late.winter + mean.Tmean.early.spring	5	8226.03	2.39	0.03
initdate.julian ~ mean.Tmean.late.winter	4	8226.38	2.73	0.02
initdate.julian ~ sum.Prcp.late.winter	4	8226.46	2.81	0.02
initdate.julian ~ mean.Tmean.early.spring	4	8226.48	2.83	0.02
initdate.julian ~ sum.Prcp.late.winter + mean.Tmean.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + sum.Prcp.late.spring	8	8226.51	2.86	0.02
initdate.julian ~ sum.Prcp.late.winter + mean.Tmean.late.winter + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring	8	8226.57	2.92	0.02
initdate.julian ~ sum.Prcp.late.spring	4	8226.60	2.95	0.02

Variable Importance

Variable	Variable Importance	Model-averaged Coefficient
mean.Tmean.late.winter	0.68	1.62
sum.Prcp.late.winter	0.65	-0.53
mean.Tmean.early.spring	0.52	-0.77

Gadwall at Grizzly Island Wildlife Area

Model Selection

Model	K	AICc	ΔAICc	Weight
initdate.julian ~ mean.Tmean.late.winter + mean.Tmean.early.spring + mean.Tmean.late.spring	6	19250.75	0.00	0.07
initdate.julian ~ mean.Tmean.late.winter + mean.Tmean.late.spring	5	19251.25	0.50	0.05
initdate.julian ~ mean.Tmean.late.winter + mean.Tmean.early.spring	5	19251.32	0.57	0.05
initdate.julian ~ mean.Tmean.late.spring	4	19251.47	0.72	0.05
initdate.julian ~ mean.Tmean.late.winter + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring	7	19251.56	0.81	0.05
initdate.julian ~ sum.Prcp.late.winter + mean.Tmean.late.winter + mean.Tmean.early.spring	6	19252.09	1.34	0.04
initdate.julian ~ sum.Prcp.late.winter + mean.Tmean.early.spring	5	19252.25	1.50	0.03
initdate.julian ~ sum.Prcp.late.winter + mean.Tmean.late.winter + mean.Tmean.early.spring + mean.Tmean.late.spring	7	19252.34	1.60	0.03
initdate.julian ~ sum.Prcp.late.winter + mean.Tmean.late.spring	5	19252.44	1.70	0.03
initdate.julian ~ mean.Tmean.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + mean.Tmean.late.spring	7	19252.64	1.89	0.03
initdate.julian ~ mean.Tmean.late.winter + sum.Prcp.late.spring + mean.Tmean.late.spring	6	19252.75	2.00	0.03
initdate.julian ~ mean.Tmean.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring	6	19252.80	2.05	0.02
initdate.julian ~ sum.Prcp.late.winter + mean.Tmean.early.spring + mean.Tmean.late.spring	6	19252.80	2.05	0.02
initdate.julian ~ sum.Prcp.late.winter + mean.Tmean.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring	7	19252.97	2.22	0.02
initdate.julian ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring	6	19253.11	2.36	0.02
initdate.julian ~ mean.Tmean.early.spring + mean.Tmean.late.spring	5	19253.19	2.44	0.02
initdate.julian ~ mean.Tmean.late.winter + sum.Prcp.early.spring + mean.Tmean.late.spring	6	19253.24	2.49	0.02
initdate.julian ~ sum.Prcp.late.winter + mean.Tmean.late.winter + mean.Tmean.late.spring	6	19253.24	2.50	0.02
initdate.julian ~ sum.Prcp.late.winter + mean.Tmean.late.winter + mean.Tmean.early.spring +	8	19253.25	2.50	0.02

	sum.Prcp.late.spring + mean.Tmean.late.spring				
initdate.julian ~	mean.Tmean.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring	8	19253.27	2.52	0.02
initdate.julian ~	mean.Tmean.late.winter + mean.Tmean.early.spring + sum.Prcp.late.spring	6	19253.31	2.56	0.02
initdate.julian ~	sum.Prcp.late.spring + mean.Tmean.late.spring	5	19253.43	2.68	0.02
initdate.julian ~	sum.Prcp.early.spring + mean.Tmean.late.spring	5	19253.47	2.72	0.02

Variable Importance

Variable	**Variable Importance**	**Model-averaged Coefficient**
mean.Tmean.late.spring	0.62	-0.68
mean.Tmean.early.spring	0.61	-1.02
mean.Tmean.late.winter	0.60	0.84

Gadwall at Conaway Ranch

Model Selection

Model	K	AICc	ΔAICc	Weight
initdate.julian ~ 1 + (1 | site) + (1 | year)	3	1247.88	0.00	0.14
initdate.julian ~ mean.Tmean.early.spring + (1 | site) + (1 | year)	4	1249.37	1.49	0.07
initdate.julian ~ sum.Prcp.late.winter + (1 | site) + (1 | year)	4	1249.75	1.87	0.05
initdate.julian ~ sum.Prcp.late.spring + (1 | site) + (1 | year)	4	1249.90	2.02	0.05
initdate.julian ~ mean.Tmean.late.spring + (1 | site) + (1 | year)	4	1249.90	2.02	0.05
initdate.julian ~ sum.Prcp.early.spring + (1 | site) + (1 | year)	4	1249.96	2.08	0.05
initdate.julian ~ mean.Tmean.late.winter + (1 | site) + (1 | year)	4	1249.98	2.09	0.05
initdate.julian ~ mean.Tmean.early.spring + mean.Tmean.late.spring + (1 | site) + (1 | year)	5	1250.81	2.93	0.03

Variable Importance

No variables in model set with Variable Importance > 0.5

10th Percentile of Nest Initiation Dates

Mallard at Grizzly Island Wildlife Area

Model Selection

Model	K	AICc	ΔAICc	Weight
nest.initdate.lower10 ~ sum.Prcp.late.winter + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring	7	2574.71	0.00	0.09
nest.initdate.lower10 ~ mean.Tmean.early.spring + mean.Tmean.late.spring	5	2575.12	0.41	0.08
nest.initdate.lower10 ~ mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring	6	2575.18	0.48	0.07
nest.initdate.lower10 ~ sum.Prcp.late.spring + mean.Tmean.late.spring	5	2575.29	0.58	0.07
nest.initdate.lower10 ~ sum.Prcp.late.winter + mean.Tmean.early.spring	5	2575.39	0.68	0.07
nest.initdate.lower10 ~ mean.Tmean.late.spring	4	2575.52	0.81	0.06
nest.initdate.lower10 ~ sum.Prcp.late.winter + mean.Tmean.early.spring + mean.Tmean.late.spring	6	2575.85	1.14	0.05
nest.initdate.lower10 ~ sum.Prcp.early.spring + mean.Tmean.early.spring + mean.Tmean.late.spring	6	2575.93	1.22	0.05
nest.initdate.lower10 ~ sum.Prcp.early.spring + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring	7	2576.02	1.31	0.05
nest.initdate.lower10 ~ sum.Prcp.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring	6	2576.05	1.34	0.05
nest.initdate.lower10 ~ mean.Tmean.early.spring	4	2576.06	1.35	0.05
nest.initdate.lower10 ~ sum.Prcp.early.spring + mean.Tmean.late.spring	5	2576.24	1.53	0.04
nest.initdate.lower10 ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring	8	2576.50	1.80	0.04
nest.initdate.lower10 ~ sum.Prcp.late.winter + mean.Tmean.early.spring + sum.Prcp.late.spring	6	2576.89	2.18	0.03
nest.initdate.lower10 ~ sum.Prcp.late.winter + sum.Prcp.late.spring + mean.Tmean.late.spring	6	2577.08	2.37	0.03
nest.initdate.lower10 ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + mean.Tmean.late.spring	7	2577.37	2.66	0.02
nest.initdate.lower10 ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring	6	2577.42	2.72	0.02

nest.initdate.lower10 ~ sum.Prcp.late.winter + mean.Tmean.late.spring	5	2577.57	2.86	0.02

Variable Importance

Variable	**Variable Importance**	**Model-averaged Coefficient**
mean.Tmean.late.spring	0.76	-1.41
mean.Tmean.early.spring	0.68	-1.52

Mallard at Conaway Ranch

Model Selection

Model	**K**	**AICc**	**ΔAICc**	**Weight**
nest.initdate.lower10 ~ 1	3	332.68	0.00	0.26
nest.initdate.lower10 ~ sum.Prcp.early.spring	4	334.76	2.08	0.09
nest.initdate.lower10 ~ sum.Prcp.late.spring	4	334.80	2.12	0.09
nest.initdate.lower10 ~ mean.Tmean.late.spring	4	335.17	2.48	0.08
nest.initdate.lower10 ~ mean.Tmean.early.spring	4	335.18	2.50	0.08
nest.initdate.lower10 ~ sum.Prcp.late.winter	4	335.19	2.51	0.08

Variable Importance

No variables in model set with Variable Importance > 0.5

Gadwall at Grizzly Island Wildlife Area

Model Selection

Model	K	AICc	ΔAICc	Weight
nest.initdate.lower10 ~ 1	3	2320.23	0.00	0.14
nest.initdate.lower10 ~ mean.Tmean.late.spring	4	2320.56	0.33	0.12
nest.initdate.lower10 ~ mean.Tmean.early.spring	4	2321.76	1.54	0.06
nest.initdate.lower10 ~ sum.Prcp.late.winter	4	2321.87	1.64	0.06
nest.initdate.lower10 ~ sum.Prcp.late.spring + mean.Tmean.late.spring	5	2322.06	1.83	0.05
nest.initdate.lower10 ~ sum.Prcp.late.spring	4	2322.24	2.02	0.05
nest.initdate.lower10 ~ sum.Prcp.early.spring	4	2322.24	2.02	0.05
nest.initdate.lower10 ~ sum.Prcp.late.winter + mean.Tmean.late.spring	5	2322.40	2.17	0.05
nest.initdate.lower10 ~ mean.Tmean.early.spring + mean.Tmean.late.spring	5	2322.56	2.33	0.04
nest.initdate.lower10 ~ sum.Prcp.early.spring + mean.Tmean.late.spring	5	2322.61	2.38	0.04
nest.initdate.lower10 ~ sum.Prcp.late.winter + mean.Tmean.early.spring	5	2322.71	2.49	0.04

Variable Importance

No variables in model set with Variable Importance > 0.5

Gadwall at Conaway Ranch

Model Selection

Model	K	AICc	ΔAICc	Weight
nest.initdate.lower10 ~ mean.Tmean.early.spring	4	202.10	0.00	0.23
nest.initdate.lower10 ~ 1	3	202.79	0.69	0.17
nest.initdate.lower10 ~ sum.Prcp.late.winter	4	204.07	1.97	0.09
nest.initdate.lower10 ~ mean.Tmean.early.spring + mean.Tmean.late.spring	5	204.64	2.54	0.07
nest.initdate.lower10 ~ sum.Prcp.late.winter + mean.Tmean.early.spring	5	204.74	2.64	0.06

Variable Importance

Variable	Variable Importance	Model-averaged Coefficient
mean.Tmean.early.spring	0.52	-1.57

Central Span Nesting Season

Mallard at Grizzly Island Wildlife Area

Model Selection

Model	K	AICc	ΔAICc	Weight
nestingseason.centralspan ~ sum.Prcp.early.spring + sum.Prcp.late.spring + sum.Prcp.early.summer	6	2647.69	0.00	0.05
nestingseason.centralspan ~ sum.Prcp.late.spring + sum.Prcp.early.summer	5	2647.76	0.07	0.05
nestingseason.centralspan ~ sum.Prcp.early.spring + mean.Tmean.early.spring + sum.Prcp.late.spring + sum.Prcp.early.summer	7	2649.37	1.68	0.02
nestingseason.centralspan ~ sum.Prcp.early.spring + sum.Prcp.late.spring + sum.Prcp.early.summer + mean.Tmean.early.summer	7	2649.40	1.71	0.02
nestingseason.centralspan ~ sum.Prcp.late.spring	4	2649.41	1.72	0.02
nestingseason.centralspan ~ sum.Prcp.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring + sum.Prcp.early.summer	7	2649.42	1.72	0.02
nestingseason.centralspan ~ mean.Tmean.late.winter + sum.Prcp.late.spring + sum.Prcp.early.summer	6	2649.48	1.79	0.02
nestingseason.centralspan ~ mean.Tmean.early.spring + sum.Prcp.late.spring + sum.Prcp.early.summer	6	2649.51	1.82	0.02
nestingseason.centralspan ~ sum.Prcp.late.winter + sum.Prcp.early.spring + sum.Prcp.late.spring + sum.Prcp.early.summer	7	2649.60	1.91	0.02
nestingseason.centralspan ~ mean.Tmean.late.winter + sum.Prcp.early.spring + sum.Prcp.late.spring + sum.Prcp.early.summer	7	2649.65	1.96	0.02
nestingseason.centralspan ~ sum.Prcp.late.spring + mean.Tmean.late.spring + sum.Prcp.early.summer	6	2649.71	2.02	0.02
nestingseason.centralspan ~ sum.Prcp.late.spring + sum.Prcp.early.summer + mean.Tmean.early.summer	6	2649.72	2.03	0.02
nestingseason.centralspan ~ sum.Prcp.late.winter + sum.Prcp.late.spring + sum.Prcp.early.summer	6	2649.82	2.13	0.02
nestingseason.centralspan ~ sum.Prcp.early.spring + sum.Prcp.late.spring	5	2649.89	2.20	0.02
nestingseason.centralspan ~ mean.Tmean.late.winter + mean.Tmean.early.spring + sum.Prcp.late.spring + sum.Prcp.early.summer	7	2650.24	2.55	0.01

nestingseason.centralspan ~ mean.Tmean.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + sum.Prcp.late.spring + sum.Prcp.early.summer	8	2650.61	2.91	0.01
nestingseason.centralspan ~ mean.Tmean.early.spring + sum.Prcp.late.spring	5	2650.64	2.95	0.01

Variable Importance

Variable	**Variable Importance**	**Model-averaged Coefficient**
sum.Prcp.late.spring	0.85	1.75
sum.Prcp.early.summer	0.65	4.93
sum.Prcp.early.spring	0.52	0.25

Mallard at Conaway Ranch

Model Selection

Model	K	AICc	ΔAICc	Weight
nestingseason.centralspan ~ mean.Tmean.early.summer	4	341.09	0.00	0.06
nestingseason.centralspan ~ 1	3	341.32	0.23	0.05
nestingseason.centralspan ~ mean.Tmean.late.winter	4	341.76	0.67	0.04
nestingseason.centralspan ~ sum.Prcp.early.spring	4	342.45	1.35	0.03
nestingseason.centralspan ~ sum.Prcp.late.spring + mean.Tmean.early.summer	5	342.82	1.72	0.03
nestingseason.centralspan ~ mean.Tmean.late.winter + sum.Prcp.late.spring	5	342.89	1.80	0.02
nestingseason.centralspan ~ sum.Prcp.early.spring + mean.Tmean.early.summer	5	343.05	1.96	0.02
nestingseason.centralspan ~ mean.Tmean.late.winter + sum.Prcp.late.spring + mean.Tmean.late.spring	6	343.30	2.21	0.02
nestingseason.centralspan ~ mean.Tmean.late.winter + sum.Prcp.early.spring	5	343.55	2.45	0.02
nestingseason.centralspan ~ mean.Tmean.late.winter + mean.Tmean.early.summer	5	343.55	2.45	0.02
nestingseason.centralspan ~ sum.Prcp.early.summer + mean.Tmean.early.summer	5	343.59	2.50	0.02
nestingseason.centralspan ~ mean.Tmean.early.spring	4	343.61	2.52	0.02
nestingseason.centralspan ~ mean.Tmean.early.spring + mean.Tmean.early.summer	5	343.64	2.55	0.02
nestingseason.centralspan ~ sum.Prcp.late.winter + mean.Tmean.early.summer	5	343.67	2.58	0.02
nestingseason.centralspan ~ mean.Tmean.late.spring	4	343.72	2.62	0.02
nestingseason.centralspan ~ mean.Tmean.late.spring + mean.Tmean.early.summer	5	343.76	2.66	0.02
nestingseason.centralspan ~ sum.Prcp.late.winter	4	343.76	2.67	0.02
nestingseason.centralspan ~ sum.Prcp.early.summer	4	343.80	2.71	0.02
nestingseason.centralspan ~ sum.Prcp.late.spring	4	343.83	2.73	0.02
nestingseason.centralspan ~ sum.Prcp.late.winter + mean.Tmean.late.winter	5	344.06	2.97	0.01

Variable Importance

No variables in model set with Variable Importance > 0.5

Gadwall at Grizzly Island Wildlife Area

Model Selection

Model	K	AICc	ΔAICc	Weight
nestingseason.centralspan ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring	6	2405.76	0.00	0.08
nestingseason.centralspan ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + sum.Prcp.late.spring	7	2406.89	1.13	0.05
nestingseason.centralspan ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + mean.Tmean.early.summer	7	2407.56	1.80	0.03
nestingseason.centralspan ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + sum.Prcp.early.summer	7	2407.64	1.88	0.03
nestingseason.centralspan ~ sum.Prcp.late.winter + mean.Tmean.early.spring + sum.Prcp.late.spring	6	2407.71	1.95	0.03
nestingseason.centralspan ~ sum.Prcp.late.winter + mean.Tmean.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring	7	2407.82	2.06	0.03
nestingseason.centralspan ~ sum.Prcp.late.winter + mean.Tmean.early.spring	5	2407.83	2.07	0.03
nestingseason.centralspan ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + mean.Tmean.late.spring	7	2407.84	2.08	0.03
nestingseason.centralspan ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring	8	2408.49	2.73	0.02
nestingseason.centralspan ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.early.summer	8	2408.62	2.86	0.02
nestingseason.centralspan ~ sum.Prcp.late.winter + sum.Prcp.late.spring	5	2408.70	2.94	0.02

Variable Importance

Variable	Variable Importance	Model-averaged Coefficient
sum.Prcp.late.winter	0.91	0.76
mean.Tmean.early.spring	0.71	-1.06
sum.Prcp.early.spring	0.59	0.31

Gadwall at Conaway Ranch

Model Selection

Model	K	AICc	ΔAICc	Weight
nestingseason.centralspan ~ mean.Tmean.early.spring	4	196.68	0.00	0.16
nestingseason.centralspan ~ mean.Tmean.early.spring + sum.Prcp.early.summer	5	198.12	1.44	0.08
nestingseason.centralspan ~ sum.Prcp.late.winter + mean.Tmean.early.spring	5	198.78	2.10	0.05
nestingseason.centralspan ~ mean.Tmean.early.spring + mean.Tmean.late.spring	5	199.42	2.74	0.04
nestingseason.centralspan ~ sum.Prcp.early.spring + mean.Tmean.early.spring	5	199.57	2.88	0.04

Variable Importance

Variable	Variable Importance	Model-averaged Coefficient
mean.Tmean.early.spring	0.78	2.98

90th Percentile of Nest Initiation Dates

Mallard at Grizzly Island Wildlife Area

Model Selection

Model	K	AICc	ΔAICc	Weight
nest.initdate.upper90 ~ sum.Prcp.late.winter + mean.Tmean.early.spring + mean.Tmean.late.spring	6	2481.51	0.00	0.10
nest.initdate.upper90 ~ sum.Prcp.late.winter + mean.Tmean.early.spring + mean.Tmean.late.spring + sum.Prcp.early.summer	7	2482.08	0.56	0.07
nest.initdate.upper90 ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + mean.Tmean.late.spring	7	2482.52	1.01	0.06
nest.initdate.upper90 ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + mean.Tmean.late.spring + sum.Prcp.early.summer	8	2482.94	1.42	0.05
nest.initdate.upper90 ~ sum.Prcp.late.winter + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring	7	2483.22	1.71	0.04
nest.initdate.upper90 ~ sum.Prcp.late.winter + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring + sum.Prcp.early.summer	8	2483.27	1.75	0.04
nest.initdate.upper90 ~ sum.Prcp.late.winter + mean.Tmean.early.spring + mean.Tmean.late.spring + mean.Tmean.early.summer	7	2483.36	1.85	0.04
nest.initdate.upper90 ~ mean.Tmean.late.spring	4	2483.48	1.97	0.04
nest.initdate.upper90 ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring + sum.Prcp.early.summer	9	2483.64	2.12	0.03
nest.initdate.upper90 ~ sum.Prcp.late.winter + mean.Tmean.early.spring + mean.Tmean.late.spring + sum.Prcp.early.summer + mean.Tmean.early.summer	8	2483.77	2.26	0.03
nest.initdate.upper90 ~ sum.Prcp.late.winter + mean.Tmean.late.spring	5	2483.87	2.36	0.03
nest.initdate.upper90 ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.late.spring	8	2483.97	2.46	0.03

nest.initdate.upper90 ~ sum.Prcp.late.winter + mean.Tmean.late.spring + sum.Prcp.early.summer	6	2484.43	2.92	0.02
nest.initdate.upper90 ~ mean.Tmean.early.spring + mean.Tmean.late.spring	5	2484.50	2.99	0.02

Variable Importance

Variable	**Variable Importance**	**Model-averaged Coefficient**
mean.Tmean.late.spring	0.94	-1.71
sum.Prcp.late.winter	0.79	0.60
mean.Tmean.early.spring	0.72	-1.37

Mallard at Conaway Ranch

Model Selection

Model	K	AICc	ΔAICc	Weight
nest.initdate.upper90 ~ sum.Prcp.late.spring + mean.Tmean.early.summer	5	277.51	0.00	0.19
nest.initdate.upper90 ~ sum.Prcp.late.spring + mean.Tmean.late.spring + mean.Tmean.early.summer	6	279.61	2.10	0.07
nest.initdate.upper90 ~ sum.Prcp.late.winter + sum.Prcp.late.spring + mean.Tmean.early.summer	6	279.65	2.14	0.07
nest.initdate.upper90 ~ sum.Prcp.early.spring + sum.Prcp.late.spring + mean.Tmean.early.summer	6	280.01	2.50	0.05
nest.initdate.upper90 ~ mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.early.summer	6	280.14	2.63	0.05
nest.initdate.upper90 ~ sum.Prcp.late.spring + sum.Prcp.early.summer + mean.Tmean.early.summer	6	280.18	2.67	0.05

Variable Importance

Variable	Variable Importance	Model-averaged Coefficient
sum.Prcp.late.spring	0.79	2.08
mean.Tmean.early.summer	0.78	-1.70

Gadwall at Grizzly Island Wildlife Area

Model Selection

Model	K	AICc	ΔAICc	Weight
nest.initdate.upper90 ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring	6	2384.41	0.00	0.06
nest.initdate.upper90 ~ sum.Prcp.late.winter + mean.Tmean.early.spring + sum.Prcp.early.summer + mean.Tmean.early.summer	7	2384.55	0.14	0.06
nest.initdate.upper90 ~ sum.Prcp.late.winter + mean.Tmean.early.spring + mean.Tmean.early.summer	6	2384.63	0.22	0.06
nest.initdate.upper90 ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + sum.Prcp.early.summer	7	2384.67	0.26	0.05
nest.initdate.upper90 ~ sum.Prcp.late.winter + mean.Tmean.early.spring	5	2385.31	0.90	0.04
nest.initdate.upper90 ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + sum.Prcp.early.summer + mean.Tmean.early.summer	8	2385.67	1.26	0.03
nest.initdate.upper90 ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + mean.Tmean.early.summer	7	2385.71	1.31	0.03
nest.initdate.upper90 ~ sum.Prcp.late.winter + mean.Tmean.early.spring + sum.Prcp.early.summer	6	2385.85	1.44	0.03
nest.initdate.upper90 ~ sum.Prcp.late.winter + mean.Tmean.early.spring + mean.Tmean.late.spring	6	2385.90	1.50	0.03
nest.initdate.upper90 ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + mean.Tmean.late.spring	7	2386.06	1.65	0.03
nest.initdate.upper90 ~ sum.Prcp.late.winter + mean.Tmean.early.spring + mean.Tmean.late.spring + mean.Tmean.early.summer	7	2386.23	1.83	0.03
nest.initdate.upper90 ~ sum.Prcp.late.winter + mean.Tmean.early.spring + mean.Tmean.late.spring + sum.Prcp.early.summer + mean.Tmean.early.summer	8	2386.28	1.87	0.02
nest.initdate.upper90 ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + mean.Tmean.late.spring + sum.Prcp.early.summer	8	2386.39	1.98	0.02
nest.initdate.upper90 ~ sum.Prcp.late.winter + mean.Tmean.late.spring	5	2386.45	2.04	0.02
nest.initdate.upper90 ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring +	7	2386.45	2.04	0.02

sum.Prcp.late.spring				
nest.initdate.upper90 ~ sum.Prcp.late.winter + mean.Tmean.early.spring + mean.Tmean.late.spring + sum.Prcp.early.summer	7	2386.48	2.07	0.02
nest.initdate.upper90 ~ sum.Prcp.late.winter + mean.Tmean.early.spring + sum.Prcp.late.spring + mean.Tmean.early.summer	7	2386.53	2.12	0.02
nest.initdate.upper90 ~ sum.Prcp.late.winter + mean.Tmean.early.spring + sum.Prcp.late.spring + sum.Prcp.early.summer + mean.Tmean.early.summer	8	2386.64	2.23	0.02
nest.initdate.upper90 ~ sum.Prcp.late.winter + sum.Prcp.early.spring + mean.Tmean.early.spring + sum.Prcp.late.spring + sum.Prcp.early.summer	8	2386.77	2.36	0.02
nest.initdate.upper90 ~ sum.Prcp.late.winter + mean.Tmean.early.spring + sum.Prcp.late.spring	6	2386.85	2.44	0.02
nest.initdate.upper90 ~ sum.Prcp.late.winter + mean.Tmean.late.spring + sum.Prcp.early.summer	6	2387.04	2.63	0.02

Variable Importance

Variable	**Variable Importance**	**Model-averaged Coefficient**
sum.Prcp.late.winter	0.95	1.19
mean.Tmean.early.spring	0.76	-1.70

Gadwall at Conaway Ranch

Model Selection

Model	K	AICc	ΔAICc	Weight
nest.initdate.upper90 ~ 1	3	196.22	0.00	0.20
nest.initdate.upper90 ~ sum.Prcp.early.spring	4	198.28	2.06	0.07
nest.initdate.upper90 ~ mean.Tmean.early.spring	4	198.54	2.32	0.06
nest.initdate.upper90 ~ mean.Tmean.early.summer	4	198.64	2.42	0.06
nest.initdate.upper90 ~ mean.Tmean.late.spring	4	198.73	2.51	0.06
nest.initdate.upper90 ~ sum.Prcp.early.summer	4	198.79	2.57	0.05
nest.initdate.upper90 ~ sum.Prcp.late.winter	4	198.95	2.73	0.05
nest.initdate.upper90 ~ sum.Prcp.late.spring	4	199.06	2.84	0.05

Variable Importance

No variables in model set with Variable Importance > 0.5

Proportion of Eggs Hatched

Mallard at Grizzly Island Wildlife Area

Model Selection

Model	K	AICc	ΔAICc	Weight
propeggshatched ~ count.extreme.high.95.Tmax + mean.Tmean.late.spring	5	9507.18	0.00	0.11
propeggshatched ~ count.extreme.high.95.Tmax + max.Tmax.late.spring	5	9508.61	1.43	0.06
propeggshatched ~ count.extreme.high.95.Tmax	4	9508.67	1.48	0.05
propeggshatched ~ count.extreme.high.95.Tmax + mean.Tmean.late.spring + max.Tmax.early.summer	6	9509.00	1.82	0.05
propeggshatched ~ count.extreme.high.95.Tmax + mean.Tmean.late.spring + sum.Prcp.early.summer	6	9509.03	1.85	0.04
propeggshatched ~ count.extreme.high.95.Tmax + mean.Tmean.late.spring + max.Tmax.late.spring	6	9509.09	1.91	0.04
propeggshatched ~ count.extreme.high.95.Tmax + sum.Prcp.late.spring + mean.Tmean.late.spring	6	9509.11	1.93	0.04
propeggshatched ~ count.extreme.high.95.Tmax + mean.Tmean.late.spring + mean.Tmean.early.summer	6	9509.13	1.95	0.04
propeggshatched ~ count.extreme.high.95.Tmax + sum.Prcp.late.spring	5	9510.11	2.93	0.03

Variable Importance

Variable	Variable Importance	Model-averaged Coefficient
count.extreme.high.95.Tmax	1.00	-0.15
mean.Tmean.late.spring	0.59	0.04

Mallard at Conaway Ranch

Model Selection

Model	K	AICc	ΔAICc	Weight
propeggshatched ~ count.extreme.high.95.Tmax + sum.Prcp.late.spring + max.Tmax.late.spring + sum.Prcp.early.summer + mean.Tmean.early.summer	8	1261.49	0.00	0.19
propeggshatched ~ count.extreme.high.95.Tmax + sum.Prcp.late.spring + max.Tmax.late.spring + mean.Tmean.early.summer	7	1263.19	1.70	0.08
propeggshatched ~ count.extreme.high.95.Tmax + sum.Prcp.late.spring + max.Tmax.late.spring + sum.Prcp.early.summer + mean.Tmean.early.summer + max.Tmax.early.summer	9	1263.50	2.00	0.07
propeggshatched ~ count.extreme.high.95.Tmax + sum.Prcp.late.spring + mean.Tmean.late.spring + max.Tmax.late.spring + sum.Prcp.early.summer + mean.Tmean.early.summer	9	1263.50	2.01	0.07

Variable Importance

Variable	Variable Importance	Model-averaged Coefficient
count.extreme.high.95.Tmax	0.99	-0.12
mean.Tmean.early.summer	0.77	-0.48
sum.Prcp.late.spring	0.72	0.40
max.Tmax.late.spring	0.64	0.19
sum.Prcp.early.summer	0.53	0.45

Gadwall at Grizzly Island Wildlife Area

Model Selection

Model	K	AICc	ΔAICc	Weight
propeggshatched ~ count.extreme.high.95.Tmax + mean.Tmean.late.spring + mean.Tmean.early.summer	6	2337.34	0.00	0.09
propeggshatched ~ count.extreme.high.95.Tmax + max.Tmax.late.spring + mean.Tmean.early.summer	6	2338.23	0.89	0.06
propeggshatched ~ count.extreme.high.95.Tmax + mean.Tmean.late.spring + max.Tmax.late.spring + mean.Tmean.early.summer	7	2338.48	1.14	0.05
propeggshatched ~ count.extreme.high.95.Tmax + mean.Tmean.late.spring + sum.Prcp.early.summer + mean.Tmean.early.summer	7	2338.80	1.45	0.04
propeggshatched ~ count.extreme.high.95.Tmax + mean.Tmean.late.spring + mean.Tmean.early.summer + max.Tmax.early.summer	7	2338.83	1.49	0.04
propeggshatched ~ count.extreme.high.95.Tmax + sum.Prcp.late.spring + mean.Tmean.late.spring + mean.Tmean.early.summer	7	2339.26	1.92	0.03
propeggshatched ~ max.Tmax.late.spring + mean.Tmean.early.summer	5	2339.32	1.97	0.03
propeggshatched ~ count.extreme.high.95.Tmax + sum.Prcp.late.spring + max.Tmax.late.spring + mean.Tmean.early.summer	7	2339.67	2.32	0.03
propeggshatched ~ count.extreme.high.95.Tmax + mean.Tmean.late.spring + sum.Prcp.early.summer + mean.Tmean.early.summer + max.Tmax.early.summer	8	2339.94	2.60	0.02
propeggshatched ~ count.extreme.high.95.Tmax + max.Tmax.late.spring + sum.Prcp.early.summer + mean.Tmean.early.summer	7	2340.07	2.73	0.02
propeggshatched ~ count.extreme.high.95.Tmax + mean.Tmean.late.spring + max.Tmax.late.spring + sum.Prcp.early.summer + mean.Tmean.early.summer	8	2340.10	2.75	0.02
propeggshatched ~ mean.Tmean.late.spring + max.Tmax.late.spring + mean.Tmean.early.summer	6	2340.22	2.88	0.02
propeggshatched ~ count.extreme.high.95.Tmax + max.Tmax.late.spring + mean.Tmean.early.summer + max.Tmax.early.summer	7	2340.23	2.89	0.02

Variable Importance

Variable	**Variable Importance**	**Model-averaged Coefficient**
mean.Tmean.early.summer	0.84	0.14
count.extreme.high.95.Tmax	0.77	-0.08
mean.Tmean.late.spring	0.59	-0.05
max.Tmax.late.spring	0.55	-0.02

Gadwall at Conaway Ranch

Model Selection

Model	K	AICc	ΔAICc	Weight
propeggshatched ~ sum.Prcp.late.spring + mean.Tmean.early.summer	5	262.48	0.00	0.08
propeggshatched ~ count.extreme.high.95.Tmax + sum.Prcp.late.spring + mean.Tmean.early.summer	6	263.94	1.46	0.04
propeggshatched ~ max.Tmax.late.spring	4	264.20	1.71	0.03
propeggshatched ~ mean.Tmean.late.spring	4	264.36	1.88	0.03
propeggshatched ~ sum.Prcp.late.spring + sum.Prcp.early.summer + mean.Tmean.early.summer	6	264.41	1.93	0.03
propeggshatched ~ mean.Tmean.late.spring + mean.Tmean.early.summer	5	264.42	1.93	0.03
propeggshatched ~ mean.Tmean.late.spring + max.Tmax.early.summer	5	264.48	1.99	0.03
propeggshatched ~ mean.Tmean.early.summer	4	264.55	2.07	0.03
propeggshatched ~ sum.Prcp.late.spring + max.Tmax.late.spring + mean.Tmean.early.summer	6	264.70	2.22	0.03
propeggshatched ~ sum.Prcp.late.spring + mean.Tmean.late.spring + mean.Tmean.early.summer	6	264.82	2.33	0.03
propeggshatched ~ sum.Prcp.late.spring + mean.Tmean.early.summer + max.Tmax.early.summer	6	264.82	2.33	0.03
propeggshatched ~ max.Tmax.late.spring + mean.Tmean.early.summer	5	265.24	2.76	0.02
propeggshatched ~ count.extreme.high.95.Tmax + mean.Tmean.late.spring + mean.Tmean.early.summer	6	265.25	2.77	0.02
propeggshatched ~ count.extreme.high.95.Tmax + max.Tmax.late.spring	5	265.43	2.95	0.02

Variable Importance

Variable	Variable Importance	Model-averaged Coefficient
mean.Tmean.early.summer	0.65	-0.35

Nest Survival

Mallard at Grizzly Island Wildlife Area

Model Selection

BASE MODEL = date.julian + nestage + adj.initdate + date.julian:adj.initdate + nestage:adj.initdate

Model	K	AICc	ΔAICc	Weight
count.extreme.high.95.Tmax + mean.Tmean + sum.Prcp + sum.Prcp.early.spring + sum.Prcp.late.spring	11	21720.42	0.00	1.00

Variable Importance

Variable	Variable Importance	Model-averaged Coefficient*
count.extreme.high.95.Tmax	1.00	0.38
mean.Tmean	1.00	-0.07
sum.Prcp	1.00	0.68
sum.Prcp.early.spring	1.00	0.03
sum.Prcp.late.spring	1.00	-0.05

**NOTE: Model averaged coefficients for nest-survival model are with respect to the logit transformation in model.*

Mallard at Conaway Ranch

Model Selection

BASE MODEL = date.julian + nestage + adj.initdate

Model	K	AICc	ΔAICc	Weight
count.extreme.high.95.Tmax + mean.Tmean + sum.Prcp.late.spring	7	1776.26	0.00	0.20
count.extreme.high.95.Tmax + mean.Tmean + sum.Prcp.early.spring	7	1776.41	0.15	0.18
count.extreme.high.95.Tmax + mean.Tmean	6	1776.62	0.36	0.16
count.extreme.high.95.Tmax + mean.Tmean + sum.Prcp.early.spring + sum.Prcp.late.spring	8	1777.40	1.14	0.11
count.extreme.high.95.Tmax + mean.Tmean + sum.Prcp + sum.Prcp.early.spring	8	1777.56	1.30	0.10
count.extreme.high.95.Tmax + mean.Tmean + sum.Prcp + sum.Prcp.late.spring	8	1777.66	1.40	0.10
count.extreme.high.95.Tmax + mean.Tmean + sum.Prcp	7	1777.94	1.68	0.09
count.extreme.high.95.Tmax + mean.Tmean + sum.Prcp + sum.Prcp.early.spring + sum.Prcp.late.spring	9	1778.67	2.41	0.06

Variable Importance

Variable	Variable Importance	Model-averaged Coefficient*
count.extreme.high.95.Tmax	1.00	0.29
mean.Tmean	1.00	-0.17
sum.Prcp.late.spring	0.47	-0.06
sum.Prcp.early.spring	0.46	-0.03

sum.Prcp	0.34	-0.22

**NOTE: Model averaged coefficients for nest-survival model are with respect to the logit transformation in model.*

Gadwall at Grizzly Island Wildlife Area

Model Selection

BASE MODEL = nestage + adj.initdate + nestage^2 + adj.initdate^2

Model	K	AICc	ΔAICc	Weight
count.extreme.high.95.Tmax + mean.Tmean + sum.Prcp	8	6183.20	0.00	0.23
count.extreme.high.95.Tmax + mean.Tmean + sum.Prcp + sum.Prcp.early.spring + sum.Prcp.late.spring	10	6183.25	0.05	0.22
count.extreme.high.95.Tmax + mean.Tmean + sum.Prcp + sum.Prcp.late.spring	9	6183.38	0.18	0.21
count.extreme.high.95.Tmax + mean.Tmean + sum.Prcp + sum.Prcp.early.spring	9	6183.89	0.69	0.16
count.extreme.high.95.Tmax + mean.Tmean + sum.Prcp.early.spring + sum.Prcp.late.spring	9	6185.52	2.33	0.07

Variable Importance

Variable	Variable Importance	Model-averaged Coefficient*
count.extreme.high.95.Tmax	1.00	0.42
mean.Tmean	1.00	-0.10
sum.Prcp	0.82	0.27
sum.Prcp.late.spring	0.55	0.03
Sum.Prcp.early.spring	0.48	-0.01

**NOTE: Model averaged coefficients for nest-survival model are with respect to the logit transformation in model.*

Gadwall at Conaway Ranch

Model Selection

BASE MODEL = nestage + adj.initdate

Model	K	AICc	ΔAICc	Weight
count.extreme.high.95.Tmax + mean.Tmean + sum.Prcp.early.spring	6	282.39	0.00	0.33
count.extreme.high.95.Tmax + mean.Tmean + sum.Prcp.early.spring + sum.Prcp.late.spring	7	284.24	1.85	0.13
count.extreme.high.95.Tmax + mean.Tmean	5	284.30	1.91	0.13
count.extreme.high.95.Tmax + mean.Tmean + sum.Prcp + sum.Prcp.early.spring	7	284.31	1.92	0.12
count.extreme.high.95.Tmax + mean.Tmean + sum.Prcp.late.spring	6	284.81	2.42	0.10

Variable Importance

Variable	Variable Importance	Model-averaged Coefficient*
count.extreme.high.95.Tmax	0.95	0.27
mean.Tmean	0.95	-0.22
sum.Prcp.early.spring	0.63	-0.09
sum.Prcp.late.spring	0.31	0.06
sum.Prcp	0.29	0.48

**NOTE: Model averaged coefficients for nest-survival model are with respect to the logit transformation in model*