

Report to Cosumnes Research Group/CALFED study  
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**Impacts of flooding and global climate cycle on Song Sparrow reproductive success at  
Cosumnes River Preserve, California, U.S.A.**

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## INTRODUCTION

Avian reproductive success can be influenced by changes in local and global climate conditions (Sillett et al. 2000, Martin 2001, Chase et al. 2005); depending on the timing of climatic events, there may be a positive or negative relationship between weather variables and reproductive success. The potential effects of climate variables on avian reproductive success are even more complex for birds that breed in seasonal floodplains and riparian zones which are subject to seasonal inundation. A disproportionate number of avian species require riparian or floodplain habitat to breed (Manley and Davidson 1993, Miller et al. 2004), yet these areas are more susceptible to flooding and climatic events than more upland habitats.

Winter rains may scour the floodplain and promote vegetative growth leading to improved nest site conditions, especially for bird species that nest in shrub or understory vegetation. Winter rains may also increase the food supply in terms of insects and seeds both before and during the breeding season. However, prolonged flood conditions may delay the onset of the breeding season and excessive precipitation during the breeding season may have a detrimental effect. Heavy rains may destroy nests or otherwise have a negative impact on nest cover, nest substrates, food availability, or some other aspect of the breeding season (DeSante and Geupel 1987, Rogers et al. 1997). Yet, late season rains that do not induce flooding may extend the breeding season by increasing the food supply or vegetative cover for nesting, especially in regions where summer rainfall is typically minimal (Chase et al. 2005). These relationships between climate and nest survival form the basis for the operational hypotheses examined in this study.

The effects of climatic events may be measured in terms of local temperature or precipitation; however, local patterns may be driven by large scale events such as the El Niño-Southern Oscillation (ENSO) phenomenon. During El Niño events, rainfall increases in some parts of the world while drought conditions occur in other regions (Holmgren et al 2001). ENSO events affect precipitation patterns in western North America (Cayan et al 1999), including Northern California, during their warm (El Niño) and cool phases (La Niña). The severity of ENSO weather patterns can be quantified using the Southern Oscillation Index. ENSO events affect terrestrial ecosystems (Holmgren et al. 2001) including landbird productivity (Grant et al. 2000, Wilson and Arcese 2003, Both and Visser 2005).

In California's Great Central Valley, less than 10% of the pre-settlement riparian habitat remains (Katibah 1984) yet this habitat is used disproportionately more than other valley habitats (Manley and Davidson 1993). Riparian habitat loss and subsequent fragmentation has had a negative impact on wildlife, including resident and migrating songbirds that require riparian habitat for nesting habitat, wintering habitat, and forage during migration. Thus there has been an unprecedented effort to restore floodplain dynamics (Florsheim, Mount, and Constantine 2006) and riparian habitats (Gardali et al. in press) in the Great Central Valley using active horticultural methods or semi-passive, process-based methods.

We were interested in examining the factors affecting avian reproductive success for riparian birds, as well as how these factors varied with restoration status, flooding, and ENSO events in a dynamic floodplain environment at the Cosumnes River Preserve in California's Central Valley. We investigated multiple individual *a priori* hypotheses in order to hierarchically build a final

model that considered the relative effects of all hypotheses on avian productivity. Data to evaluate these hypotheses were collected on Song Sparrows (*Melospiza melodia*) over an eleven year period at six plots which included a variety of vegetation/restoration ages and restoration approaches.

The Restoration hypothesis considered whether a study site was restored or not (binary), the age of the restoration/regeneration, and the restoration group type (process-based, horticultural/process mix, or remnant riparian). These variables are known to affect avian abundance and richness in parts of the Central Valley (Gardali et al. in press) and may also influence reproduction.

The Nest height hypothesis considered the placement of the nest in terms of nest height, as this variable may be especially critical in a dynamic floodplain environment. Tall nests may avoid inundation events, but they may also be more vulnerable to visually oriented nest predators.

The Nest age hypothesis considered linear, quadratic, cubic, and quartic relationships of age on nest survival. Daily nest survival rates often vary with age according to these different power functions because the risk of nest mortality varies with the stage of the nesting cycle (laying, eggs, nestlings). Recent studies have shown that daily nest survival varies with age in a cubic manner (Grant et al. 2005) or a quartic manner (Nur et al. 2004). While we were not directly interested in nest age effects for this study, we wanted to include and control for these effects in our analyses.

The Date hypothesis considered whether date in the season had an effect on nest survival in a linear or quadratic manner. Other studies have shown that nest survival varies quadratically during the season (Rogers et al. 1997). While we were not directly interested in date effects for this study, we wanted to include and control for these effects in our analyses.

The Breeding season hydrology hypothesis considered rainfall during the regular (March-May) and late breeding season (June-July), as well as the number of flood days during the breeding season and the monthly volume of water during first and second halves of the breeding season. Flood days are the number of days where volume exceeded flood stage on the river (22.65 m<sup>3</sup>/s).

The Non-breeding season hydrology hypothesis considered winter flooding, winter rainfall, and winter water volume, as well as annual rainfall.

The ENSO hypothesis considered variables associated with the SOI including the SOI for the first 4 months of the year, SOI for the last 4 months of the previous year, SOI for that combined 8 month period, and annual (12 month period from May of previous the year through April of current year) SOI. ENSO events have been shown to have an influence on avian productivity or life history traits in other studies (Grant et al. 2000, Both and Visser 2005) including research on Song Sparrows (Wilson and Arcese 2003).

## Methods

### Study Site

Data were collected within the Cosumnes River Preserve (CRP), near Galt, California, from April through August at six study plots within the Cosumnes River floodplain (Figure 1, Table 1). Data were collected from 1995 to 2005, but not all plots were surveyed in every year. The plots included two mature riparian forest sites (Tall Forest and Orr Forest), as well as four restoration plots at a range of successional stages (Cottonwood Grove, Triangle Plot, Middle Breach, and Tall Forest West). All restoration plots were undergoing semi-passive “process-based” restoration, except the latter (Tall Forest West) which was undergoing active horticultural restoration. Year of restoration varied among restored sites (Table 1). In our analyses we considered the effects of individual site, restoration age, restoration status (restored or not), and restoration type (none, process-based, active).

Table 1. Cosumnes nest plots, plot codes, survey effort, plot size, and restoration status.

<b>Nest Plot</b>	<b>Code</b>	<b>Years monitored</b>	<b>Plot Size (ha)</b>	<b>Year Restored</b>	<b>Type of Restoration</b>
Orr Forest	ORFO	2003-2004	15.4	NA	none
Tall Forest	TAFO	1995-2005	12.0	NA	none
Cottonwood Grove	CWGR	1995-2005	8.0	1984	process based
Middle Breach	MIBR	2002-2005	10.7	1995	process based
Triangle Plot	TRPL	2002-2005	10.3	1997	process based
Tall Forest West	TFWE	1996-2005	20.0	1985	active

### Avian Monitoring

Nest finding and monitoring were conducted from April through August and followed the guidelines outlined in Martin and Geupel (1993). Nests were located at all stages (construction, egg-laying, incubation, and nestling) and visited approximately every three days until the nest fledged young or failed. At each visit we recorded the date and nest contents. A nest was

considered successful if at least one Song Sparrow young fledged. Precautionary measures were employed during nest finding and monitoring activities to minimize disturbance. Precautionary measures included limiting the time at the nest, minimizing disturbance to the area around a nest, staying clear of nest sites when predators were detected nearby, and avoiding creating trails directly to the nest. After a nest was no longer active we measured the height from ground for that nest. We collected data on all species' active nests that were encountered, but we only present Song Sparrows here, because we had the greatest sample sizes for this species (n=966 nests).

### **Hydrology and Climate Data**

We used a variety of hydrological and climate variables to address our *a priori* hypotheses about nest success.

*Precipitation:* Daily accumulated precipitation data were acquired from two weather stations within 20 miles of the CRP. We used these data to determine monthly total precipitation throughout the time period of the study, as well as winter rainfall (October through February) [winterrain], breeding season rain (March-May) [breedrain], and late breeding season rains (June-July) [lateSummer\_rain].

*Hydrology:* River flow data were recorded at the USGS Michigan bar sensor on the Cosumnes River which is approximately 50 km upstream from the Cosumnes River Preserve and known to accurately predict flood conditions on the floodplain (Hammersmark et al. 2005). Data were obtained from the U.S. Geological Survey's National Water Information System (USGS 2005).

Mean daily discharge was used to calculate the total volume of water per month and year [tot\_vol]. We further broke volume into the early (March-April) [early\_vol] and late breeding season (May-June) [late\_vol]. Flood days included the number of days a nest was active in which the water discharge volume exceeded flood stage for the river [tot\_fdays]. We further broke these into winter flood days (October of previous year through February of current year) [winter flood], early breeding season flood days (March-April) [early\_fld], and nest flood days (number of days at floodstage for each active nest) [nest\_fld] in our analyses.

*Global Climate:* The Southern Oscillation Index (SOI) an index of El Niño Southern Oscillation (ENSO) strength was used to link local patterns to hemispheric level oscillations. El Niño events have negative SOI values and La Niña events have positive SOI values. Because there may be a delay in the effect of ENSO events on breeding productivity, we considered SOI over the last four months of previous year (Sept-Dec) [SOI\_4moPrevYr], SOI over the first four months of the year (Jan-Apr) [SOI\_last4moCurrYr], SOI over an eight month period (Sept-Apr) [SOI\_8mo], and annual SOI [SOI\_ann] (last 8 months of previous year and first 4 months of current year). SOI data were obtained from the National Center for Atmospheric Research (Boulder, CO).

## **Analyses**

We used an information-theoretic approach to evaluate relationships between nest survival and the covariates of interest (Burnham and Anderson 2002). Nest survival analyses were calculated with the logistic exposure method, a type of discrete survival analysis (using a modified logit link function and a binomial distribution [Shaffer 2004]). Analyses were conducted using the



GENMOD procedure in SAS (SAS Institute, Cary North Carolina). Each interval between nest checks was treated as an observation in the analyses. We assumed nest checks occurred every three days as this corresponds to the median interval.

Burnham and Anderson (2002) recommend assessing the goodness-of-fit of the global model prior to assessing the candidate models. This is necessary to determine that the data are not over-dispersed in order to meet the assumptions for model selection. We used a likelihood-ratio test to compare the global model with the null model. The global model indicated that the data were not significantly over-dispersed (Hosmer-Lemeshow Goodness of Fit test  $\chi^2=12.71$ ,  $df=8$ ,  $P>0.122$ , Hosmer-Lemeshow 2000), so we proceeded to examine each of the candidate models.

We took a hierarchical model selection approach in our analyses. The first hierarchical level involved first examining the individual hypotheses. When examining competing hypotheses we also included a constant survival model (null). The null hypothesis candidate model asserted that nest survival was constant and not influenced by any of our variables of interest. The global model included all the variables related to an individual hypothesis. For each of the individual hypotheses we determined the most important variable for that hypothesis using model selection. Our second hierarchical level involved taking the top model from the individual hypotheses and evaluating them together in a final model building exercise.

We calculated Akaike's information criteria (AIC) corrected for small sample size (AICc), as well as Akaike weights ( $w_i$ ) and  $\Delta AICc$  (difference between that model and the model with the lowest AICc value) to identify the best of the candidate models. The model with the smallest

AIC is the best approximating model for the data; Akaike weights represent the likelihood of a given model and evidence ratios can be constructed as the ratio of weights for the two models being compared (Burnham and Anderson 2002). Models with lower AICc and  $\Delta\text{AICc}$ , and a greater Akaike weight ( $w_i$ ) have more support. Models with  $\Delta\text{AICc}$  less than 2 were considered as having substantial support, models with  $\Delta\text{AICc}$  within 2-7 units of the best model were interpreted as having less support, and models greater 10 were considered to have little support (Burnham and Anderson 2002). We then advanced the top model from each of the hypotheses into the final model.

For the final model building we evaluated all combinations and subsets of the variables that were advanced into the final candidate model set. We used model averaging to reduce problems with model-selection uncertainty; however most of the individual hypotheses had a clear top model (based on the model weights).

## **Results**

### **Individual Hypotheses**

#### *Restoration Hypotheses*

Model selection results for the restoration variables indicated that restoration type (active, process-based or no restoration) had the strongest effect on nest survival among the candidate restoration models that we considered. Restoration type accounted for 100% of the variation relative to the other restoration variables that were considered and was the only candidate model for this hypothesis with a  $\Delta\text{AICc} < 2$ . The effect of restoration type (with 3 restoration categories) was greater than the effect of restoration status (with 2 restoration categories, restored

or not) which indicated that it was necessary to separate process-based and active restoration categories. We did not find any support for an effect of restoration age, although this has been detected in other studies with a greater range in restoration ages and a greater sample size of plots and plot-years (Gardali et al. 2004). We probably did not have sufficient sample sizes of nest plots to detect a restoration age effect. We also did not find support for an effect of individual sites relative to the other models considered – if there is an effect of individual sites, it is less than the effect of restoration type. Restoration type was advanced into the final candidate model set.

Model	log likelihood	deviance	n	k	AIC	AICc	$\Delta$ AICc	w Akaike
<b>Restoration_Type</b>	<b>-1308.90</b>	<b>2617.80</b>	<b>8721</b>	<b>3</b>	<b>2623.80</b>	<b>2623.81</b>	<b>0</b>	<b>1</b>
Restoration Status	-1346.93	2693.86	8721	2	2697.86	2697.86	74.05	0
Restoration Age	-1347.52	2695.04	8721	2	2699.04	2699.04	75.24	0
Site	-2013.04	4026.08	8721	6	4038.08	4038.09	1414.28	0
Constant surv.	-2052.79	4105.57	8721	1	4107.57	4107.57	1483.77	0

### *Nest Height*

We only had one metric of nest height so we could only compare this variable to a null model with constant survival. Including a nest height variable was an improvement over a constant survival model that did not include nest height. Model selection results indicated support for an effect of nest height on nest survival with a  $\Delta$ AICc < 2 and 97% of the variation explained relative to the constant survival model. We advanced the nest height variable into the final candidate model set.

Model	log likelihood	deviance	n	k	AIC	AICc	$\Delta$ AICc	w Akaike
<b>NestHt</b>	<b>-2048.39</b>	<b>4096.78</b>	<b>8721</b>	<b>2</b>	<b>4100.78</b>	<b>4100.78</b>	<b>0</b>	<b>0.96758</b>
Constant surv.	-2052.79	4105.57	8721	1	4107.57	4107.57	6.79	0.03242

### *Age Hypotheses*

Including variables that accounted for nest age was an improvement over a constant survival model that did not include age. Model selection results for the nest age hypothesis indicated that the cubic effect of age had the strongest effect on nest survival among the candidate age models that we considered. The cubic effect accounted for 98% of the variation relative to the quadratic and linear age relationships. The cubic age model was also the only candidate model for this hypothesis with a  $\Delta AICc < 2$ . We also considered a fourth order relationship for age, but the maximum likelihood estimate for this model would not converge. We advanced the cubic age model ( $Age^3+Age^2+Age$ ) into the final candidate model set.

Model	log likelihood	deviance	n	k	AIC	AICc	$\Delta AICc$	w Akaike
<b><math>Age^3+Age^2+Age</math></b>	<b>-1996.41</b>	<b>3992.83</b>	<b>8721</b>	<b>4</b>	<b>4000.83</b>	<b>4000.83</b>	<b>0</b>	
<b>0.98027</b>								
Age <sup>2</sup> +Age	-2001.32	4002.64	8721	3	4008.64	4008.64	7.811	0.01973
Age	-2051.28	4102.56	8721	2	4106.56	4106.56	105.732	0
Constant surv.	-2052.79	4105.57	8721	1	4107.57	4107.57	106.743	0

### *Date Hypothesis*

Including variables that accounted for date was an improvement over a constant survival model that did not include date. Model selection results for the date hypothesis indicated that the quadratic effect of date had the strongest effect on nest survival. The quadratic date effect accounted for 99.9% of the variation relative to the linear date relationship. The quadratic date model was also the only candidate model for this hypothesis with a  $\Delta AICc < 2$ . We advanced the quadratic date model ( $Date^2+Date$ ) into the final candidate model set.

Model	log likelihood	deviance	n	k	AICc	$\Delta AICc$	w Akaike
<b><math>date^2+date</math></b>	<b>-2013.11</b>	<b>4026.22</b>	<b>8721</b>	<b>3</b>	<b>4032.23</b>	<b>0.0000</b>	<b>0.99995</b>
date	-2024.03	4048.06	8721	2	4052.07	19.8392	0.00005
const. survival	-2052.79	4105.57	8721	1	4107.57	75.3482	0

*Breeding season hydrology hypothesis*

Model selection results for the breeding season hydrological variables indicated that the number of days of flooding while a nest was active had the strongest effect on nest survival among the candidate models that we considered. This variable [nest\_fld] accounted for 97.7% of the variation relative to the other variables that were considered and was the only candidate model for this hypothesis with a  $\Delta AICc < 2$ . The next best model was average volume of water in the latter part of the breeding season which was a similar metric to nest flood days. The variable nest flood days was advanced into the final candidate model set.

Model	Logli ke	devi ance	n	k	AI Cc	$\Delta AICc$	w_Akai ke
<b>nest_fld</b>	<b>-2038. 22</b>	<b>4076. 44</b>	<b>8721</b>	<b>2</b>	<b>4080. 44</b>	<b>0. 0000</b>	<b>0. 97664</b>
late_vol	-2042. 66	4085. 32	8721	2	4089. 32	8. 8855	0. 01149
breed_rain	-2043. 32	4086. 65	8721	2	4090. 65	10. 2093	0. 00593
Global	-2043. 32	4086. 65	8721	8	4090. 65	10. 2093	0. 00593
lateSummer_rain	-2049. 28	4098. 56	8721	2	4102. 56	22. 1190	0. 00002
constant_survival	-2052. 79	4105. 57	8721	1	4107. 57	27. 1362	0. 00000
early_vol	-2051. 98	4103. 96	8721	2	4107. 97	27. 5279	0. 00000
early_fdays	-2052. 46	4104. 93	8721	2	4108. 93	28. 4898	0. 00000
late_fdays	-2052. 79	4105. 57	8721	2	4109. 58	29. 1368	0. 00000

*Non-breeding season hydrology hypothesis*

Model selection results for the non-breeding season hydrological variables indicated that the number of days of winter flooding had the strongest effect on nest survival among the candidate models that we considered. Winter flooding accounted for 55.5% of the variation relative to the other variables that were considered and was the only candidate model for this hypothesis with a  $\Delta AICc < 2$ . The variable winter flood days was advanced into the final candidate model set.

Model	Logli ke	devi ance	k	AI Cc	$\Delta AICc$	w_Akai ke
<b>wint_flood</b>	<b>-2046. 86</b>	<b>4093. 72</b>	<b>2</b>	<b>4097. 72</b>	<b>0. 00000</b>	<b>0. 55497</b>
tot_fdays	-2048. 20	4096. 41	2	4100. 41	2. 69318	0. 14436
tot_vol	-2048. 20	4096. 41	2	4100. 41	2. 69318	0. 14436
global	-2048. 20	4096. 41	5	4100. 41	2. 69318	0. 14436
winter_rain	-2051. 11	4102. 21	2	4106. 21	8. 49532	0. 00793
const. survival	-2052. 79	4105. 57	1	4107. 57	9. 85774	0. 00402

### *ENSO Hypotheses*

All models that included variables that accounted for ENSO events were improvements over a constant survival model that did not include ENSO variables. Model selection results for the ENSO hypotheses indicated that the average SOI measured in the last four months of the previous year had the strongest effect on nest survival among the candidate ENSO models that we considered. This variable [SOI\_4moPrevYr] accounted for 81.9% of the variation relative to the other variables that were considered and was the only candidate model for this hypothesis with a  $\Delta AICc < 2$ . This ENSO variable was advanced into the final candidate model set.

Model	log likelihood	deviance	n	k	AIC	AICc	$\Delta AICc$	w Akaike
<b>SOI_4moPrevYr</b>	-2028.48	4056.97	8721	2	4060.97	4060.97	0.0000	<b>0.81946</b>
SOI_ann	-2030.86	4061.72	8721	2	4065.72	4065.73	4.7544	0.07605
SOI_8mo	-2031.14	4062.29	8721	2	4066.29	4066.29	5.3178	0.05738
Global	-2028.35	4056.70	8721	5	4066.70	4066.71	5.7357	0.04656
SOI_4moCurrYr	-2035.81	4071.62	8721	2	4075.62	4075.62	14.6508	0.00054
Constant surv.	-2052.79	4105.57	8721	1	4107.57	4107.57	46.6032	0

### **Final Candidate Model Set**

Final candidate models were built based on the results of the individual hypotheses and included restoration type, nest height, nest age (cubic), julian date (quadratic), the number of flood days while a nest was active, winter flood days, and the SOI during the last four months of the previous year.

We considered all possible additive subsets of the variables restoration type, nest height, nest flood days, winter flood days, and the SOI during the last four months of the previous year with the caveat that the cubic age and quadratic date effects were included in every model. The cubic age effect was the most parsimonious model for the nest age hypothesis. Because nest age is

known to be an important factor in nest success (Grant et al. 2005), the cubic age effect (with main effects) was included in every final candidate model to control for this effect. Similarly, julian date is known to be an important factor in nest success, including studies of Song Sparrows (Rogers et al. 1997) so we included a quadratic date effect (with main effects) in every candidate model to control for this effect.

We allowed for interactions of restoration type with nest height, SOI, nest flood days, and winter flood days because we hypothesized that the effects of these variables could vary among types of restoration (e.g. the effect of nest height on nest survival may be more important in process-based restoration areas which generally have less vegetative cover than in more mature riparian areas). If interactions were included in a model, then their main effects were also specified in the model. Interactions required that we specify a reference category which serves as the basis of comparison. We chose the un-restored remnant sites restoration as the reference category for the interactions. The candidate model set also included a constant survival model and a global model (with all variables and interactions). We evaluated a total of 97 candidate models in the final model building exercise.

### **Final Model Analysis**

In the final candidate model set, the top model included restoration type, nest flood, winter flood, SOI (measured in the last four months of the previous year), nest height, and interactions between restoration type and winter flood, nest flood, and nest height (Table 2). This model accounted for 72% of the total model weight among the candidate models considered and was

the only model with  $\Delta AICc < 2$ . All of the other candidate models where  $\Delta AICc < 10$  included similar suites of variables (Table 2).

Table 2. Model selection results for final candidate models where  $\Delta AICc < 10$ . Each model included a cubic age effect ( $age^3 + age^2 + age$ ) and a quadratic julian date effect ( $date^2 + date$ ) as well as the variables indicated below.  $N_{eff}$  is 8721 for each model.

Model	Restoration Type	Nest Flood	Winter Flood	SOI	Nest Ht	Rest* Winter Flood	Rest* Nest Flood	Rest* Nest Ht	Deviance	k	AICc	$\Delta AICc$	Wt
1	x	x	x	x	x	x	x	x	3774.7	18	3810.7	0.00	0.72
2	x	x	x	x	x	x	x	x	3773.0	20	3813.1	2.37	0.22
3	x	x	x	x		x	x		3787.7	15	3817.8	7.05	0.02
4	x	x	x	x	x	x	x		3786.4	16	3818.4	7.67	0.02
5	x		x	x	x	x		x	3789.9	15	3820.0	9.21	0.01
6	x	x	x	x	x	x		x	3788.5	16	3820.5	9.78	0.01

We model averaged the parameter estimates for all 97 models to obtain unconditional estimates and standard errors (Table 3) and to guard against model uncertainty (Burnham and Anderson 2002). We also noted those parameters in which the 95% confidence interval excluded zero as this indicates that estimates are reliable. Our model averaged estimates were consistent with the top model (Table 2) indicating that in addition to date and age effects, there are effects of restoration type, nest flooding, SOI, and interactive effects of restoration type with nest height and winter flooding.



Table 3. Model averaged parameter estimates from 97 final candidate models including unconditional standard errors. If the 95% confidence interval for the estimate excludes zero it is marked with an asterisk. For restoration type, level = 0 for active restoration, level = 1 for semi-passive restoration, level = 2 for remnant riparian (the reference category).

Parameter	level	Parameter Estimate	SE	CI
Intercept		9.058903	0.996276	*
age <sup>3</sup>		-0.00025	9.73E-05	*
age <sup>2</sup>		0.017535	0.004019	*
age		-0.30682	0.048431	*
date <sup>2</sup>		0.00021	4.69E-05	*
date		-0.07073	0.013552	*
Restoration Type	0	0.149931	0.241061	
Restoration type	1	0.1615	0.175505	
Restoration type	2	0	0	
Nest flood		0.154363	0.055717	*
Winter flood		0.00114	0.003007	
SOI		0.132771	0.027611	*
Nest ht		0.003656	0.002304	
Nest flood*Type	0	-0.47474	0.163851	*
Nest flood*Type	1	-0.20968	0.075851	*
Nest flood*Type	2	0	0	
Nest ht*Type	0	-0.00885	0.005771	
Nest ht*Type	1	-0.00897	0.00307	*
Nest ht*Type	2	0	0	
Winter flood*Type	0	0.037254	0.009346	*
Winter flood*Type	1	0.004224	0.005886	
Winter flood*Type	2	0	0	
SOI*Type	0	0.010937	0.025063	
SOI*Type	1	-0.01	0.023586	
SOI*Type	2	0	0	

## Discussion

Collectively our results indicate that local and global weather effects are impacting avian nest success at Cosumnes. Local effects are mediated by the type of restoration (active, semi-passive, or remnant riparian) whereas global effects (SOI) occur regardless of restoration type. The local and global effects on nest success occur indirectly during the winter months prior to the breeding season in terms of winter floods and SOI. Local effects also occurred directly during the breeding season in terms of spring floods and nest height.

Local effects are manifested in terms of flooding which has an impact on nest survival both during the winter preceding breeding, and while nests are active. Flooding was consistently a more important method of describing hydrography (versus volume or precipitation). The magnitude and direction of the relationships with flooding varied among plots and is related to type of restoration (active or semi-passive). For example winter flooding had a definite positive effect on active restoration sites and a weak positive effect on passive restoration sites (although the confidence intervals overlapped with zero for the latter so this effect cannot be separated from a null effect). Winter flooding may promote vegetative growth to improve nest conditions or food supply during the spring breeding season, especially at early successional sites. However, flooding during the nest cycle had a negative impact on nest survival at active and passive restoration sites (relative to remnant sites). The magnitude of the nest flooding effect varied among remnant and restoration plots.

Booth, Mount, and Viers (In Press) categorized water year types (WYT) and their relative distribution in the Cosumnes watershed over a hundred year hydrograph. WYT-6 consists of a

year with a very wet winter but a relatively dry spring that does not lead to inundation of the floodplain into the late spring. WYT-6 would provide favorable conditions for song sparrow nest survival. Conversely, WYT-3 describes a year with a relatively dry winter but a relatively wet spring. Presumably, this water year type would occur when winter rainfall does not generate large flood events but enough snowmelt and/or abundant spring precipitation leads to inundation of the floodplain into the late spring. WYT-3 would provide unfavorable conditions for song sparrow nest survival. Booth, Mount, and Viers (In Press) found that the frequency of WYT-6 was increasing as the frequency of WYT-3 was decreasing (over a hundred year hydrograph). This overall pattern is favorable for song sparrow nest survival in future years.

Global manifestations of weather effects were also evident at Cosumnes. ENSO events as measured by SOI had a positive impact on productivity. This means that La Niña years (with their positive SOI values) are better for nest success than El Niño years (with negative SOI values). ENSO events have the greatest impact during the last four months of the year preceding the breeding season, so they are probably affecting succession or some aspect of the winter vegetation growth or food supply. The El Niño effect was consistent across plots and restoration types (e.g. active versus passive). There was not a significant interaction between SOI and restoration type in the top models shown in Table 2 and model averaged coefficients for this interaction had confidence intervals that over-lapped with zero (indicating that there is not an interaction). It is intuitive that ENSO events would affect all plots similarly as these are global effects.

The data for nest height indicate that there is an interaction between nest height and type of restoration plot. Nest success was greater for lower nests (closer to the ground) at active and passive restoration sites (relative to remnant sites). This seems counterintuitive, especially given the negative effect of flooding on nest success. It would seem that higher nests would avoid flooding. However in restored sites, there may be a dearth of potential “high” nest sites available to breeding birds. Moreover, in restored sites (both active and passive) higher nests may be more visible to visually oriented predators since the surrounding vegetation is not as high (Chalfoun et al. 2002).

Our results indicating a cubic relationship with age and a quadratic relationship for date are consistent with other studies and typical for an open-cup nesting passerine species. These results suggest that aside from extrinsic factors such as flooding, precipitation, and nest site location, daily nest survival varies temporally and also with the stage of the nest cycle. Rogers et al. (1997) also found a quadratic date relationship in a song sparrow population in which nest success increased at the beginning of the breeding season and later decreased. Grant et al. (2005) found a cubic age relationship in a population of clay-colored sparrows which reflected the vulnerability to predation within and among different nest stages (e.g. empty nest being built versus eggs versus nestlings). New statistical techniques (Shaffer 2004) allow us to better assess age effects (Grant et al. 2005) whereas previous nest survival statistics (e.g. Mayfield 1975) assumed that nest survival was constant with age and/or stage.

Our results illuminate the need for restoration practitioners and land managers to consider climatic uncertainty when determining the efficacy of restoration efforts for ground and shrub

nesting passerine birds. While managers cannot control local or global climatic variability, where possible managers should promote winter flooding and curb flooding events during the breeding season. Managers should also be that aware nest survival (and reproductive success) is not only affected by direct events in the breeding season, but also indirectly by events during the winter preceding breeding. In particular winter flooding or winter management activities that promote vegetative growth should be encouraged (to improve nest conditions or food supply during the following spring breeding season).

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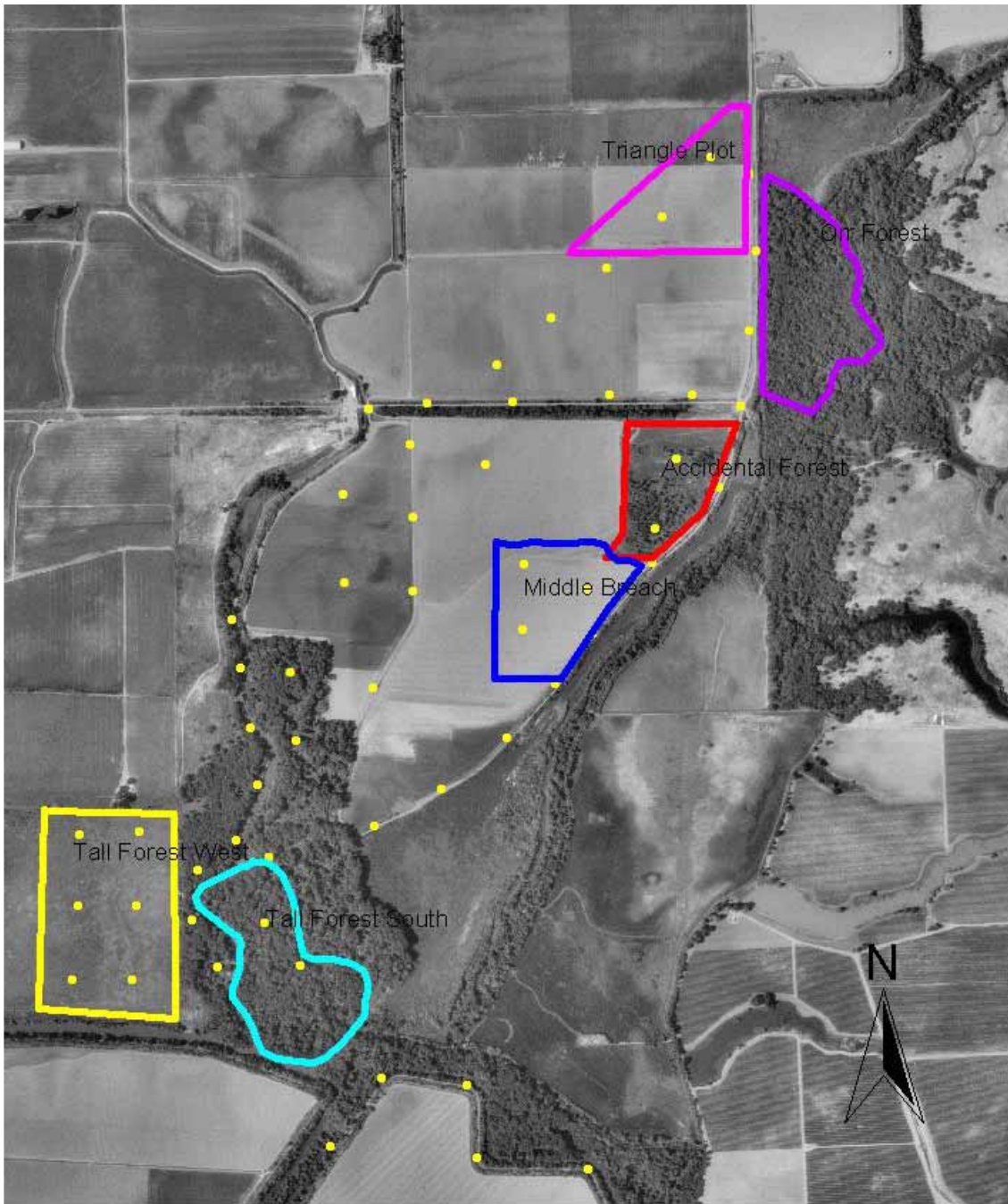
## Literature Cited

- Booth, E.G., J.F. Mount, and J.H. Viers. In Press. Hydrologic Variability of the Cosumnes River Floodplain. San Francisco Estuary and Watershed Science.
- Both, C., and M. E. Visser. 2005. The effect of climate change on the correlation between avian life-history traits. *Global Change Biology* 11:1606-1613.
- Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inferences: a practical information-theoretic approach. Second edition. Springer-Verlag, New York.
- Chalfoun, A. D., F. R. Thompson III, and M. J. Ratnaswamy. 2002. Nest predators and fragmentation: a review and meta-analysis. *Conservation Biology* 16: 306-318.
- Chase, M.K. 2005. Effects of weather and population density on reproductive success and population dynamics in a song sparrow (*Melospiza melodia*) population: a long-term study. *Auk* 122:571-592.
- Cayan, D.R., K.T. Redmond, and L.G. Riddle. 1999. ENSO and hydrologic extremes in the Western United States. *J. of Climatology* 12: 2881-2893.
- DeSante, D.F. & G.R. Geupel. 1987. Landbird productivity in central coastal California: the relationship to annual rainfall and a reproductive failure in 1986. *The Condor* 89(3):636-653.
- Florsheim, J.L., Mount, J.F., and Constantine, C.R. 2006. A geomorphic monitoring and adaptive assessment framework to assess the effect of lowland floodplain river restoration on sediment continuity. *River Research and Applications*.
- Gardali, T., A.L. Holmes, S. Small, N. Nur, G.R. Geupel, and G.H. Golet. In press. Abundance patterns of landbirds in restored and remnant riparian forests on the Sacramento River, California, U.S.A. *Restoration Ecology*.
- Grant, T. A., T. L. Shaffer, E. M. Madden, P.J. Pietz. 2005. Time specific variation in passerine nest survival: New insights into old questions. *Auk* 122:661-672.
- Grant, P. R., B. R. Grant, L. F. Keller, and K. Petren. 2000. Effects of El Niño events on Darwin's Finch productivity. *Ecology* 81:2442-2457.
- Hammersmark, C. T., Fleenor, W. E. and Schladow, S. G. 2005. Simulation of flood impact and habitat extent for a tidal freshwater marsh restoration. *Ecological Engineering* 25(2): 137-152.
- Holmgren, M., M. Scheffer, E. Ezcurra, J.R. Gutiérrez & G.M.J. Mohren 2001. El Niño effects on the dynamics of terrestrial ecosystems. *Trends in Ecology and Evolution* 16(2): 89-94.

- Hosmer, D.W., & Lemeshow, S. 2000. Applied logistic regression (2<sup>nd</sup> Edition). New York: Wiley.
- Katibah, E. F. 1984. A brief history of riparian forests in the Central Valley of California, in California Riparian Systems: Ecology, Conservation, and Productive Management (R. E. Warner and K. M. Hendrix, eds.). Univ. of Cal. Press Ltd. London, England.
- Manley, P. and C. Davidson. 1993. A risk analysis of Neotropical migrant birds in California. USFS Report, Region 5. San Francisco, CA.
- Martin, T.E. 2001. Abiotic vs. biotic influences on habitat selection of coexisting species: climate change impacts? Ecology 82 (1): 175-188.
- Martin, T. E., and G. R. Geupel. 1993. Nest-monitoring plots: Methods for locating nests and monitoring success. Journal of Field Ornithology 64: 507-519.
- Mayfield, H. F. 1975. Suggestions for calculating nest success. Wilson Bulletin. 87:456-466.
- Miller, J.R., M.D. Dixon, and M.G. Turner. 2004. Response of avian communities in large-river floodplains to environmental variation at multiple scales. Ecological Applications 14:1394-1410.
- Nur, N., A.L. Holmes, and G.R. Geupel. 2004. Use of Survival Time Analysis to analyze nesting success in birds: an example using Loggerhead Shrikes. Condor 106:457-471
- Rogers, C.M., M.J. Taitt, J.N.M. Smith, and G. Jongejan. 1997. Nest predation and cowbird parasitism create a demographic sink in wetland-breeding Song Sparrows. Condor 99:622-633.
- Sillett, T.S.; Holmes, R.T.; and Sherry, T.W. 2000. Impacts of a global climate cycle on population dynamics of a migratory songbird. Science 288 (5473): 2040-2042.
- Shaffer, T. L. 2004. A unified approach to analyzing nest success. Auk 121:526-540.
- (USGS) United States Geological Survey. 2005. National Water Information System (NWISWeb) data available on the World Wide Web.
- Wilson, S., and P. Arcese. 2003. El Niño drives timing of breeding but not population growth in the Song Sparrow (*Melospiza melodia*). Proceedings of the National Academy of Sciences USA 100:11139-11142.



Figure 1. Map of Study Area, depicting six study plots: Triangle Plot, Orr Forest, Accidental Forest (=Cottonwood Grove), Middle Breach, Tall Forest South (=Tall Forest), and Tall Forest West.



Polygons - nest monitoring  
Points - point count census

200 0 200 400 Meters