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INTERIOR LEAST TERN (*STERNULA ANTILLARUM ATHALASSOS*) AND PIPING PLOVER (*CHARADRIUS MELODUS*) NEST AND BROOD SURVIVAL AT MANAGED, OFF-CHANNEL SITES ALONG THE CENTRAL PLATTE RIVER, 2001–2015

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Abstract.– The Platte River Recovery Implementation Program (Program) and its partners invested substantial resources in creating and managing off-channel nesting habitat for interior least terns (*Sternula antillarum athalassos*) and piping plovers (*Charadrius melodus*) along the central Platte River in Nebraska. Among other things, management activities implemented at nesting sites to increase nest and brood survival included tree removal, predator trapping, construction of a water barrier surrounding the nesting area and installation of predator fences. We used 15 years of data at off-channel sites along the central Platte River to assess the influence of several biotic and abiotic factors on the survival of interior least tern and piping plover nests and broods. We observed high survival rates for interior least tern and piping plover nests and broods as 2/3 of interior least tern and 3/4 of piping plover nests were successful and 3/4 of all interior least tern and piping plover broods were successful. We found productivity of interior least terns and piping plovers was reduced during both the nesting and brood rearing stage by climactic factors rather than factors for which the Program can manage. As such, we conclude habitat management activities implemented at off-channel sites to date are sufficient for maintaining high levels of productivity for interior least terns and piping plovers along the central Platte River.

Key Words.– Central Platte River, *Charadrius melodus*, interior least tern, off-channel habitat, piping plover, sandpit, *Sternula antillarum athalassos*, survival

Running Head.– TERN & PLOVER NEST & BROOD SURVIVAL

The Platte River Recovery Implementation Program (Program) is tasked with improving interior least terns (*Sternula antillarum athalassos*; hereafter, least tern) and piping plovers (*Charadrius melodus*) use and productivity along 145 km of the Platte River in central Nebraska, USA. Program activities in this reach, known as the Associated Habitat Reach (AHR), are intended to mitigate declines in species habitat suitability due to water development in the Platte River basin (Department of the Interior, 2006). As such, the Program invested substantial resources in creating and maintaining habitat for threatened and endangered species within the AHR. Least terns and piping plovers primarily nest on off-channel habitat along the central Platte River. Several off-channel sites have been created and managed specifically to provide nesting areas alongside channels of the central Platte River for least terns and piping plovers (Program 2006). Fifteen years of implementing a standardized monitoring protocol in the AHR provided sufficient information to explore factors hypothesized to influence productivity of least terns and piping plovers at off-channel sites along the central Platte River. Such factors include: site; year; date; storms; breeding pair density; deviation in the temperature from the average temperature observed during the nesting season; distance to predator perch; and elevation above water.

Several climate-related conditions have been noted to influence avian productivity. Daily survival rate (DSR) is generally assumed to be highest when nests are established close to the peak of breeding season as opposed to very early or late in the season (Murphy et al. 2000). Timing of nesting during the breeding season has been observed to influence breeding success with higher productivity observed when temperatures are not too cold or hot. Extreme daily minimum and maximum temperatures are thought to negatively impact productivity, especially maximum temperatures (Jenks-Jay 1982, Krogh and Schweitzer 1999, Schweitzer and Leslie 1999, Harris et al. 2005). Extreme weather events (e.g. hail, intense rain, etc.) can also have detrimental impacts on nesting birds. Increasing the frequency of exposure to such events has been found to decrease DSR for nests and broods (Dinan 1982, Harris et al. 2005, Brooks et al. 2013). Inundation can greatly reduce least tern and piping plover productivity (Faanes 1983, Sidle et al. 1992). Greater elevation above water was assumed to result in an increase in overall nest and brood survival.

Inter- and intra-specific interactions have been found to influence least tern and piping plover productivity. The density of breeding pairs on a site may influence DSR through inter- and intra-specific interactions (Burger 1987 and 1988, Anteau et al. 2014). Predation has also been noted to influence least tern and piping plover productivity (Kirsch 1996, Kruse et al. 2001, Catlin et al. 2011, Brooks et al. 2013). Active management to reduce mammalian predation with predator fencing and trapping efforts was in place across all nesting sites, but avian predation has not been implemented on the central Platte River. Nests established closer to wooded areas that provide predator perches for avian species are thought to experience greater predation and have a lower DSR (Maxson and Haws 2000, Kruse et al. 2001, Murphy et al. 2003). It is also believed that piping plovers defend territories that maximize the amount of suitable foraging area.

We limited our scope to least tern and piping plover productivity on managed off-channel sites within the AHR. Off-channel sites without management activities and all in-channel sites were excluded from this investigation due to variability of site conditions and the limited amount of nesting activity. These sites accounted for <5% of all nests and broods within the AHR. The objectives of our study include quantifying least tern and piping plover nest and brood survival across years and sites and identifying important management actions and environmental and ecological conditions that influence least tern and piping plover productivity within the AHR. Identifying these factors is an important step in prioritizing and designing management strategies for increasing reproductive success. Results of this study will be used to help understand factors that limit productivity on managed off-channel sites and may provide empirically-driven modifications to current off-channel management practices to improve least tern and piping plover productivity.

METHODS

Study Area

The AHR is a 145 km reach extending from Lexington, NE downstream to Chapman, NE and encompasses the central Platte River channel and off-channel habitat within three and one half miles of the river (Fig. 1). Only three managed off-channel nest sites were present within the AHR from 2001–2007, but accumulation of land and management activities increased the number of managed sites to nine by 2013; all of which were managed through 2015 (Table 1). Likewise, the amount of available nesting habitat at all managed sites was constant from 2001–2007, increased from 2008–2013, and remained stable from 2014–2015. Among other things, management activities at each of the sites has included predator fencing and trapping, pre-emergent herbicide application, and tree removal. Predator fencing and trapping have not occurred at Trust Wildrose East.

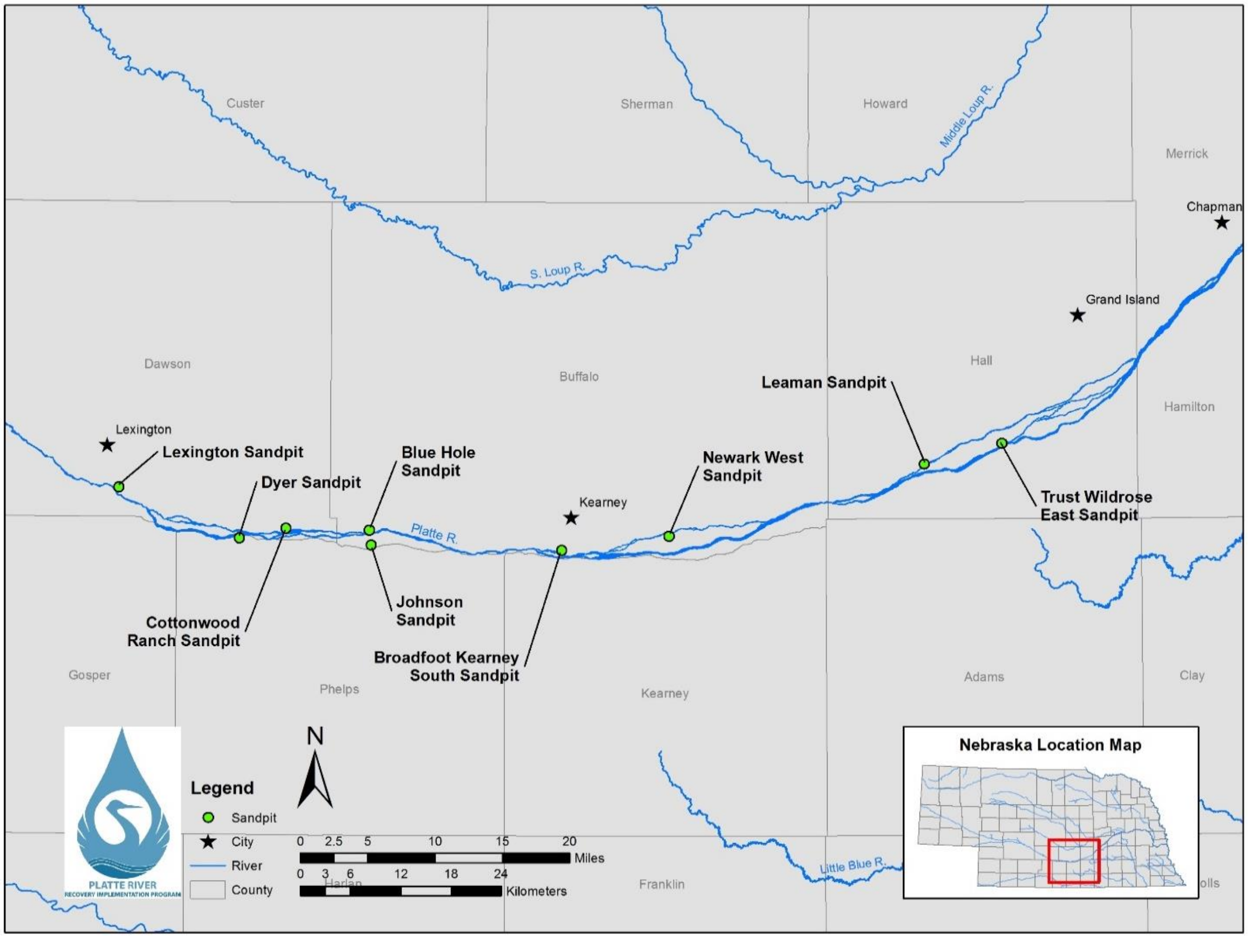

Figure 1. Associated Habitat Reach (AHR) of the central Platte River extending from Lexington downstream to Chapman, NE. Nine managed, off-channel nesting sites were included in the productivity analysis and were included as point features.

Table 1. Managed, off-channel nesting sites for interior least tern (*Sternula antillarum athalassos*) and piping plover (*Charadrius melodus*) in the Associated Habitat Reach of the central Platte River extending from Lexington to Chapman, Nebraska.

Site	Year Initiated	Hectare
Lexington	Prior to 2001	7
Dyer	2010	8
Cottonwood Ranch	2011	7
Blue Hole	Prior to 2001	11
Johnson	Prior to 2001	2
Broadfoot Kearney	2010	7
Newark West	2011	5
Leaman	2013	5
Trust Wildrose East	2008	1

Data

Off-channel nesting areas within the AHR were monitored at least twice per week from outside (2001–2015) as well as from within (2009–2015) the nesting colonies. All nests were monitored until they hatched or failed and broods were monitored until they failed or the chicks fledged. Among other things, we documented the initiation date, location, and fate of all nests as well as the fate of all broods observed. If a brood was observed but the associated nest was not, the brood was still included in the analysis. We also recorded the cause of nest or brood failure when evidence was present.

ArcGIS and the Program’s aerial imagery, collected on an annual basis, were used to measure distances of each nest to the waterline, nearest predator perch, and the nearest least tern and piping plover nest present when each nest was initiated. We used the suitable nesting area at each site to determine the nesting density for each species and site annually. We collected weather data from the National Oceanic and Atmospheric Administration (NOAA) station nearest each site and filled in missing information using data from Weather Underground (https://www.wunderground.com/). Weather stations, usually located at the nearest city or airport, were located from 6 – 40 km from each of the managed nesting sites. Given these distances, storm events, such as heavy rain and hail, recorded at each station may not accurately represent whether the event actually occurred at the site. As such, we used notes within our nest monitoring data regarding nest and brood failures due to weather to get the most accurate information on when sites were exposed to storm events. We did, however, use weather data from the NOAA station nearest each site to confirm weather events when nests and broods were recorded to have failed due to weather.

Statistical Analyses

To utilize productivity information for nest and brood survival analyses, several pieces of information were required including: 1) the day the nest or brood was found; 2) the last day the nest or brood was active; 3) the day the nest or brood was fated; 4) nest or brood fate (successful or fledged=0, respectively, or failed=1); and 5) the frequency of nests and broods with each history (frequency = 1). Days were standardized to only include the breeding season for least terns and piping plovers, which we designated as 15 April – 15 September.

We calculated DSR and the incubation and brooding period survival rates (DSR^n) where *n* is 21 days for least tern nests and broods and 28 days for piping plover nests and broods. We use logistic regression models with a logit link function:

$$DSR_i = \frac{\exp(\beta_0 + \sum_j \beta_j\, x_{ij})}{1 + \exp(\beta_0 + \sum_j \beta_j\, x_{ij})}$$

where *i* is day, *j* is the covariate, and β_j is the coefficient of the j^{th} covariate (Rotella et al. 2000).

Covariates were included as *a priori* hypotheses described below and included: site; year; date; deviation in the maximum and minimum temperature from the average observed during the nesting season; storms; distance to predator perch; elevation above water; amount of waterline within a 1.30 ha area (average nest density) around each nest, and breeding pair density. Hypotheses tested include DSR was consistent across nest sites (NS), year, and date and that maximum and minimum temperature deviation (MaxTD and MinTD, respectively), exposure to storms (S), distance to predator perch (DPP), waterline length (WLL), elevation above water (EAW), and breeding pair density (BPD) influence DSR.

Given the intensity of survey efforts, the day a nest or brood was first found was assumed to closely approximate the initiation date. Thus, date of first observation was used to investigate how timing during the breeding season influenced nest and brood survival. Based on the distribution of first nest and brood observations, standard deviations were calculated for each nest and/or brood. The same procedure was performed for minimum and maximum temperatures, which allowed for investigation of how extreme temperatures influence survival. Storm events were nest specific and identified as any weather event attributed to the failure of at least one nest or brood at a site. Densities of breeding pairs were calculated daily at each nest site for each species and an average breeding pair density was calculated during individual nesting or brooding periods. Given the elevations across off-channel sites does not change through time, we used LiDAR data collected by the Program to calculate the elevation of each nest above the waterline. We included covariates in 12 *a priori* models to quantify hypothesized relationships of daily survival rates of nests and nine *a priori* models of daily survival rates of broods for each species, both of which included null models for comparison (Table 2).

Table 2. *A priori* models used to estimate incubation and brooding period survival for interior least tern (*Sternula antillarum athalassos)* and piping plover (*Charadrius melodus*) nests and broods within the AHR, 2001–2015.

	Nest Survival		Brood Survival	
Model	Model Type	Covariates[1]	Model Type	Covariates[1]
1	Constant	Null	Constant	Null
2	Spatial	NS	Spatial	Nest Site
3	Weather	MaxTD	Weather	MaxTD
4	Weather	MinTD	Weather	MinTD
5	Weather	S	Weather	S
6	Ecological	BPD	Ecological	BPD
7	Habitat	EAW	Temporal	ID
8	Temporal	ID	Weather	MaxTD+MinTD+S
9	Temporal	Year	Habitat	WLL
10	Habitat	DPP + EAW		
11	Habitat	WLL		
12	Weather	MaxTD+MinTD+S		

[1] Breeding Pair Density (BPD) was species specific

We used the nest survival model in package RMARK in Program R for nest and brood survival analyses (Dinsmore et al. 2002, Laake 2013, R Development Core Team 2015). Models were compared using Akaike Information Criterion adjusted for small sample size (AICc). We reported DSR for nests and broods along with relationships of important covariates in the top models on reproductive success of least terns and piping plovers. When multiple models had ΔAIC ≤2.0, we considered the most parsimonious model the best model to safeguard against overly complex selections.

RESULTS

Least Tern Productivity

We observed 947 least tern nests with enough information to determine nest fate with certainty in the 9 managed off channel sites within the AHR, 2001–2015. Six hundred and fifteen nests were documented as successful and thus apparent nest survival averaged 65%. Of the 593 broods initially observed with enough information to determine fate, 450 broods were determined to have fledged at least one chick giving an average apparent brood survival of 76%. Estimates of true nest and brood survival were very similar to their respective apparent survival rates (Table 3). The number of least tern nests and broods was fairly stable from 2001–2009 and increased greatly as more off-channel habitat was created (Fig. 2). The highest number of nests and broods were observed in 2015 (149 nests, 101 broods) whereas the lowest number of nests were observed in 2001 (24 nests) and the lowest number of broods in 2001, 2006 and 2008 (19 broods). Blue Hole had by far the most least tern nests and broods from 2001–2015, but Leaman had the highest numbers of nests and broods per year (28.7 and 16.7, respectively; Tables 3 and 4). Site specific DSR of nests ranged from 0.971 to 0.990 and brood survival ranged from 0.974 to 0.993. Incubation period survival ranged from 0.537 to 0.810 and brooding period survival ranged from 0.573 to 0.860 cross all off-channel nesting sites.

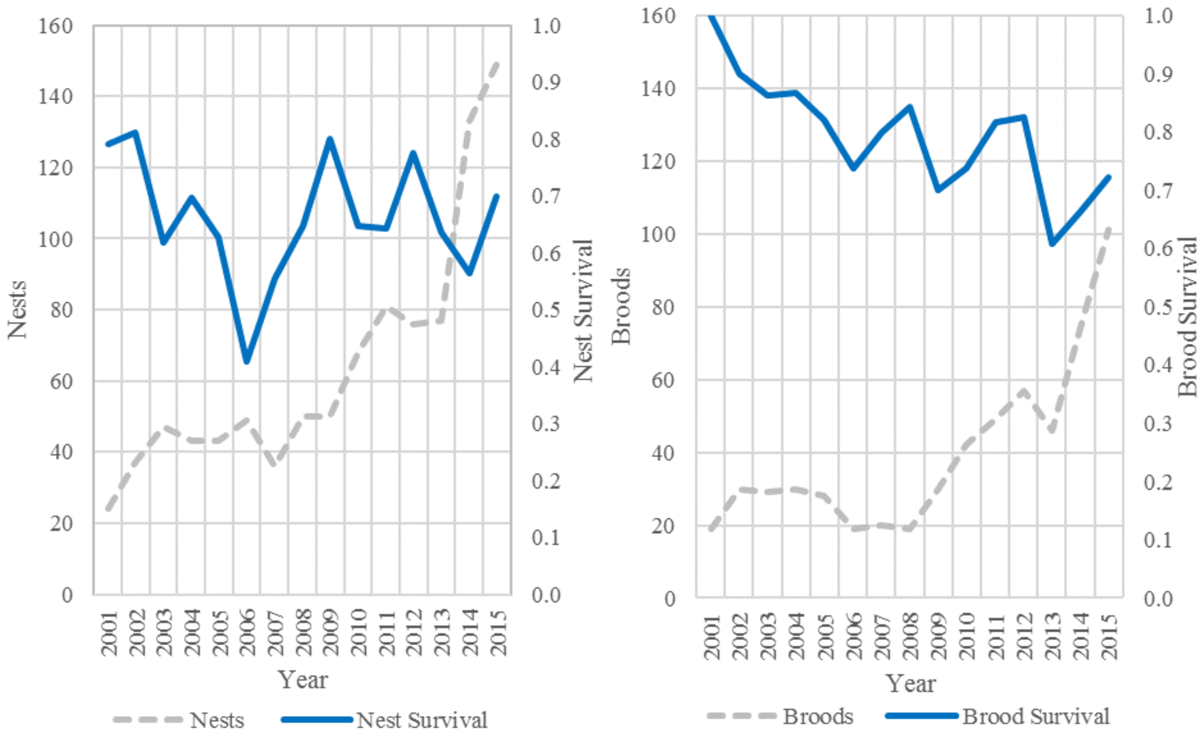

Figure 2. Number of interior least tern (*Sternula antillarum athalassos*) nests (left) and broods (right) with a known fate observed each year and probability of nest (left) and brood (right) survival at 9 managed off-channel sites within the AHR, 2001–2015.

Table 3. Site specific nest numbers and nest survival model estimated survival rates of least terns (*Sternula antillarum athalassos)* at 9 managed, off-channel sites in the AHR, 2001–2015.

Site	# Nests	# Nests Lost	Exposure Days	DSR	LCL	UCL	Nest Survival	LCL	UCL
Blue Hole	304	115	4908.5	0.976	0.971	0.980	0.602	0.543	0.656
Broadfoot Kearney South	80	28	1410	0.979	0.969	0.986	0.646	0.517	0.749
Cottonwood Ranch Sandpit	29	8	531	0.985	0.969	0.992	0.723	0.515	0.854
Dyer Sandpit	33	8	649	0.987	0.974	0.994	0.767	0.581	0.878
Johnson Sandpit	85	36	1431	0.975	0.964	0.983	0.587	0.459	0.694
Leaman Sandpit	86	36	1414	0.974	0.963	0.982	0.578	0.451	0.686
Lexington Sandpit	188	58	3169	0.981	0.974	0.986	0.672	0.579	0.749
Newark Sandpit	70	31	1046.5	0.971	0.957	0.980	0.537	0.396	0.661
Trust Wildrose East	72	12	1,176	0.990	0.982	0.995	0.810	0.676	0.893
All Sites	**947**	**332**	**15620**	**0.979**	**0.976**	**0.981**	**0.635**	**0.602**	**0.665**

Table 4. Site specific numbers of broods and nest survival model estimated daily survival rates for interior least tern (*Sternula antillarum athalassos)* broods at 9 managed, off-channel sites in the AHR, 2001–2015.

Site	Broods	Broods Lost	Exposure Days	DSR	LCL	UCL	Brood Survival	LCL	UCL
Blue Hole	184	33	3325	0.990	0.985	0.993	0.807	0.736	0.861
Broadfoot Kearney South	48	11	765.5	0.983	0.967	0.992	0.703	0.496	0.838
Cottonwood Ranch Sandpit	21	10	374.5	0.974	0.946	0.988	0.573	0.312	0.768
Dyer Sandpit	23	10	405.5	0.974	0.948	0.987	0.576	0.325	0.764
Johnson Sandpit	45	11	764	0.983	0.967	0.992	0.703	0.496	0.838
Leaman Sandpit	50	19	914	0.981	0.966	0.990	0.670	0.481	0.804
Lexington Sandpit	123	23	2145	0.990	0.982	0.994	0.802	0.678	0.882
Newark Sandpit	39	9	694	0.986	0.971	0.993	0.743	0.535	0.868
Trust Wildrose East	60	7	1,063	0.993	0.984	0.997	0.860	0.711	0.936
All Sites	**593**	**133**	**10450.5**	**0.987**	**0.984**	**0.989**	**0.758**	**0.718**	**0.793**

Piping Plover Productivity

From 2001 to 2015, 323 piping plover nests with enough information to determine nest fate were documented at the 9 managed off-channel sites within the AHR (Table 5). We observed 249 nests that were successful so apparent nest survival averaged 77% (Fig. 3). One-hundred and ninety-one broods fledged at least one chick of the 254 broods initially observed with enough information to determine fate; thus, apparent brood survival averaged 75%. Several nests were not observed before hatching which accounts for more broods being analyzed than successful nests counted. True estimates of nest and brood survival were slightly higher than apparent survival percentages (Tables 5 and 6). The number of piping plover nests and broods was fairly stable from 2001 to 2009 and increased greatly when more off-channel habitat was constructed by the Program (Fig. 3). Similar to least terns, Blue Hole had by far the most piping plover nests and broods, but Broadfoot Kearney South had the highest number of nests and broods each year (8.6 and 5.2, respectively; Tables 5 and 6). The greatest number of nests was observed in 2015 (46 nests) whereas the greatest number of broods were observed in 2014 and 2015 (32 broods). The lowest number of nests was observed in 2001 (8 nests); however, 2 nests were missed and 1 nest failed so 9 broods were tracked to fledging. Thus we observed the lowest number of piping plover broods in 2008 (8 broods). Site specific DSR ranged from 0.985 to 0.996 for nests and from 0.972 to 0.997 for broods (Fig. 3). Incubation and brooding period survival ranged from 0.727 to 0.925 and from 0.557 to 0.937, respectively (Table 6).

223 **Table 5**. Site specific number of piping plover (*Charadrius melodus*) nests and nest survival model estimated daily survival rates at 9
224 managed off-channel sites in the Associated Habitat Reach, 2001–2015.

Site	# Nests	# Nests Lost	Exposure Days	DSR	LCL	UCL	Nest survival	LCL	UCL
Blue Hole	111	20	2220	0.991	0.986	0.994	0.823	0.739	0.882
Broadfoot Kearney South	41	13	950.5	0.987	0.974	0.994	0.760	0.571	0.874
Cottonwood Ranch	5	1	131.5	0.992	0.945	0.999	0.850	0.305	0.979
Dyer	24	5	579.5	0.991	0.977	0.997	0.830	0.610	0.933
Johnson	33	7	640	0.989	0.974	0.995	0.789	0.572	0.905
Leaman	10	1	275	0.996	0.973	1.000	0.925	0.560	0.990
Lexington	67	20	1358.5	0.985	0.972	0.992	0.727	0.554	0.842
Newark	14	4	325.5	0.988	0.964	0.996	0.769	0.466	0.914
Trust Wildrose East	18	3	393.5	0.992	0.972	0.997	0.837	0.552	0.949
All Sites	**323**	**74**	**6874**	**0.989**	**0.986**	**0.991**	**0.794**	**0.748**	**0.832**

225 **Table 6**. Site specific numbers of piping plover (*Charadrius melodus*) broods and nest survival model estimated daily survival rates at
226 9 managed off-channel sites in the Associated Habitat Reach, 2001–2015.

Site	# Broods	# Broods Lost	Exposure Days	DSR	LCL	UCL	Brood Survival	LCL	UCL
Blue Hole	92	6	2205.5	0.997	0.993	0.999	0.937	0.865	0.971
Broadfoot Kearney South	26	12	463.5	0.974	0.932	0.990	0.575	0.229	0.814
Cottonwood Ranch	4	1	94.5	0.989	0.915	0.999	0.793	0.154	0.973
Dyer Sandpit	18	10	404.5	0.975	0.933	0.991	0.585	0.234	0.822
Johnson Sandpit	27	11	483.5	0.972	0.929	0.990	0.557	0.211	0.805
Leaman Sandpit	9	2	216.5	0.990	0.953	0.998	0.815	0.367	0.960
Lexington Sandpit	53	16	1061	0.985	0.961	0.994	0.721	0.430	0.882
Newark Sandpit	10	1	255.5	0.996	0.966	0.999	0.916	0.485	0.989
Trust Wildrose East	15	4	359	0.988	0.959	0.997	0.780	0.419	0.932
All Sites	**254**	**63**	**5543.5**	**0.988**	**0.984**	**0.991**	**0.774**	**0.718**	**0.819**

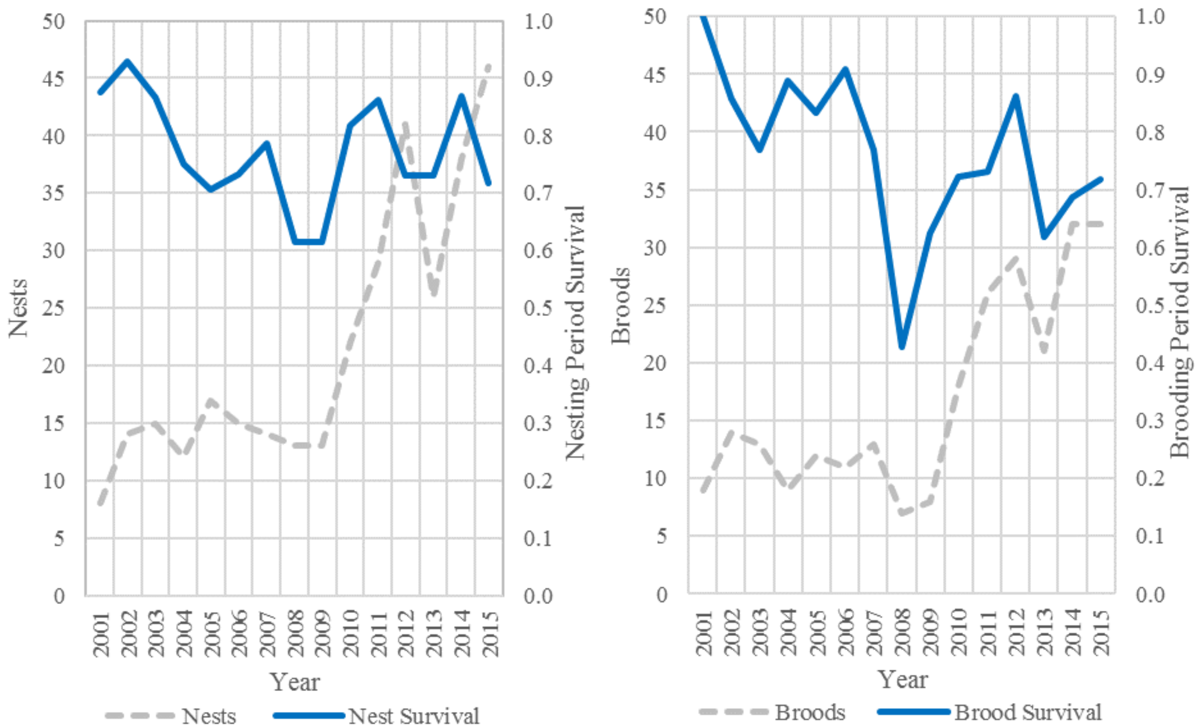

Figure 3. Number of piping plover (*Charadrius melodus*) nests (left) and broods (right) with a known fate observed each year and nest (left) and brood survival (right) at 9 managed off-channel sites in the Associated Habitat Reach, 2001–2015.

Least Tern Nest and Brood Survival

Weather related covariates, including minimum temperature deviation, maximum temperature deviation, and storm events, were include in the model that best explained patterns of least tern daily nest survival (Table 7). Survival decreased as minimum and maximum temperatures deviated from the mean (min = 10° C, max = 35° C). The negative pattern was especially prominent for the maximum temperature (Fig. 4). As storm events increased, a minimal decrease in survival was also observed (Fig. 4). Maximum temperature deviation was also found to be important for predicting least tern brood survival (Table 8). As maximum temperature deviated from average, daily survival decreased and broods that experienced high and low maximum temperatures had very low survival rates (Fig. 5).

Table 7. Top 5 models, as ranked by AICc statistic, that best predict interior least tern (*Sternula antillarum athalassos)* nest survival. The null model had an ΔAICc value >69.

Model	Parameters	AICc	ΔAICc	Weight	Deviance
MinTD + MaxTD + S	4	2759.04	0.00	1.00	2751.03
MinTD	2	2770.97	11.93	0.00	2766.97
Date	2	2800.75	41.71	0.00	2796.75
MaxTD	2	2810.30	51.26	0.00	2806.30
BPD	2	2815.14	56.10	0.00	2811.14

Table 8. Top 5 models, as ranked by AICc statistic, that best predict interior least tern (*Sternula antillarum athalassos*) brood survival. The null model had an ΔAICc value >24.

Model	Parameters	AICc	ΔAICc	Weight	Deviance
MaxTD	2	1159.67	0.00	0.69	1155.67
MinTD + MaxTD + S	4	1161.24	1.57	0.31	1153.24
Date	2	1172.24	12.56	0.00	1168.23
Year	2	1175.61	15.94	0.00	1171.61
MinTD	2	1180.92	21.24	0.00	1176.92

Piping Plover Nest and Brood Survival

Maximum temperature deviation was also important for predicting daily nest survival for piping plovers (Table 9). As maximum temperature deviated from the average nesting period temperature, daily nest survival decreased to where high and low maximum temperatures had very low survival rates (Fig. 6). Differences in survival between sites was the best predictor of the daily and brood survival of piping plover (Table 10). Blue Hole experienced the highest survival rate whereas Johnson had the lowest (Table 6).

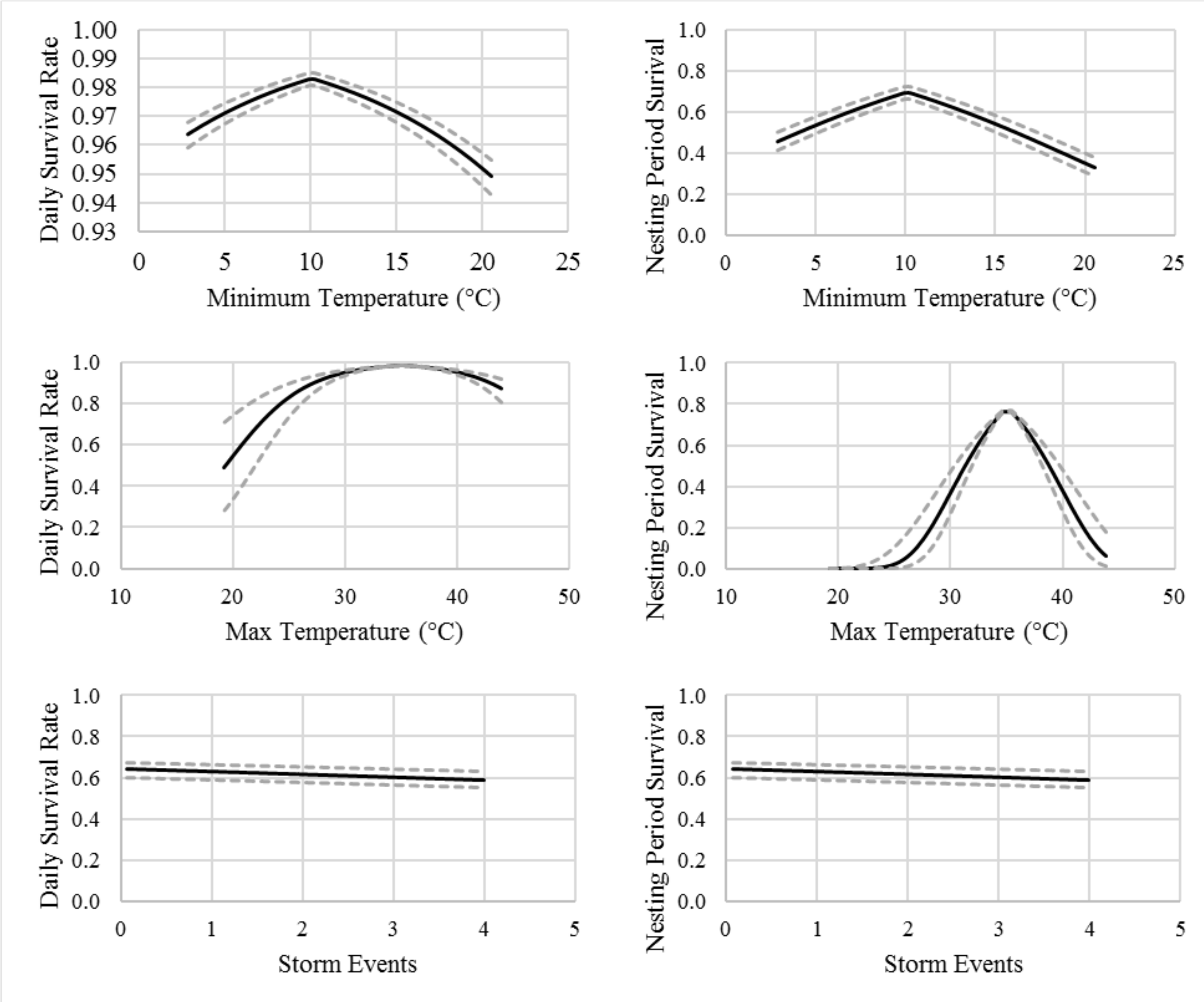

Figure 4. Influence of covariates included in the best model, with 95% confidence intervals, on predicted daily (DSR; left) and nest period survival rate (DSR^{21}; right) for interior least tern (*Sternula antillarum athalassos)* nests.

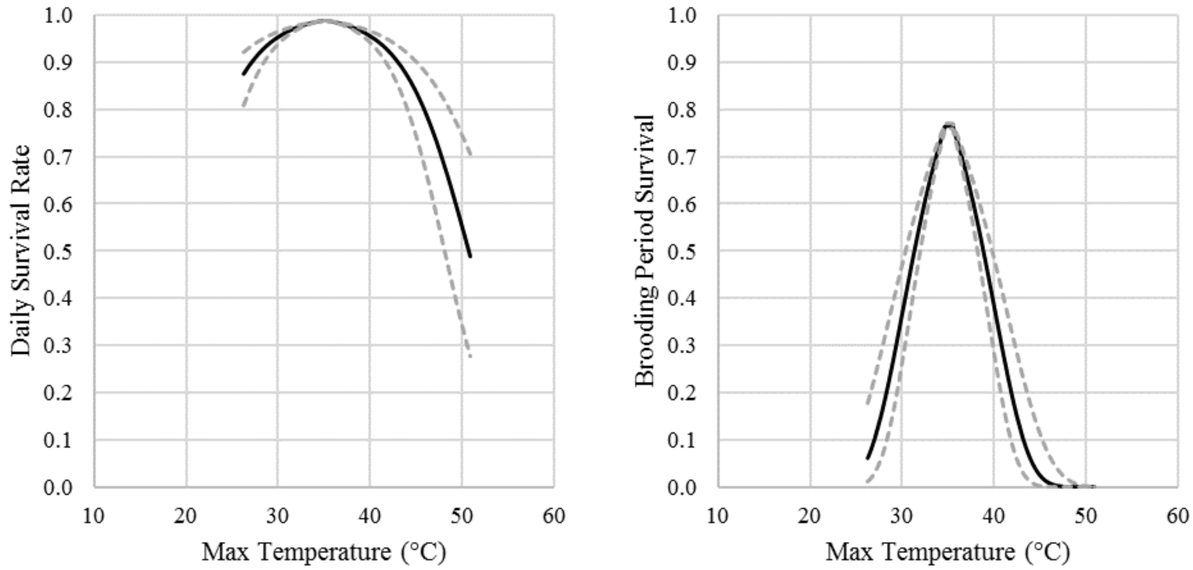

Figure 5. Influence of maximum temperature on predicted daily (DSR; left) and brooding period survival rates (DSR^{21}; right) for interior least tern (*Sternula antillarum athalassos)* broods with 95% confidence intervals.

Table 9. Top 5 models, as ranked by AICc statistic, that best predict piping plover (*Charadrius melodus*) nest survival.

Model	Parameters	AICc	ΔAICc	Weight	Deviance
MaxTD	2	707.10	0.00	0.87	703.10
MinTD + MaxTD + S	4	710.93	3.83	0.13	702.93
EAW	2	735.10	28.00	0.00	731.10
DPP + EAW	3	735.29	28.19	0.00	729.29
Null	1	735.81	28.70	0.00	733.81

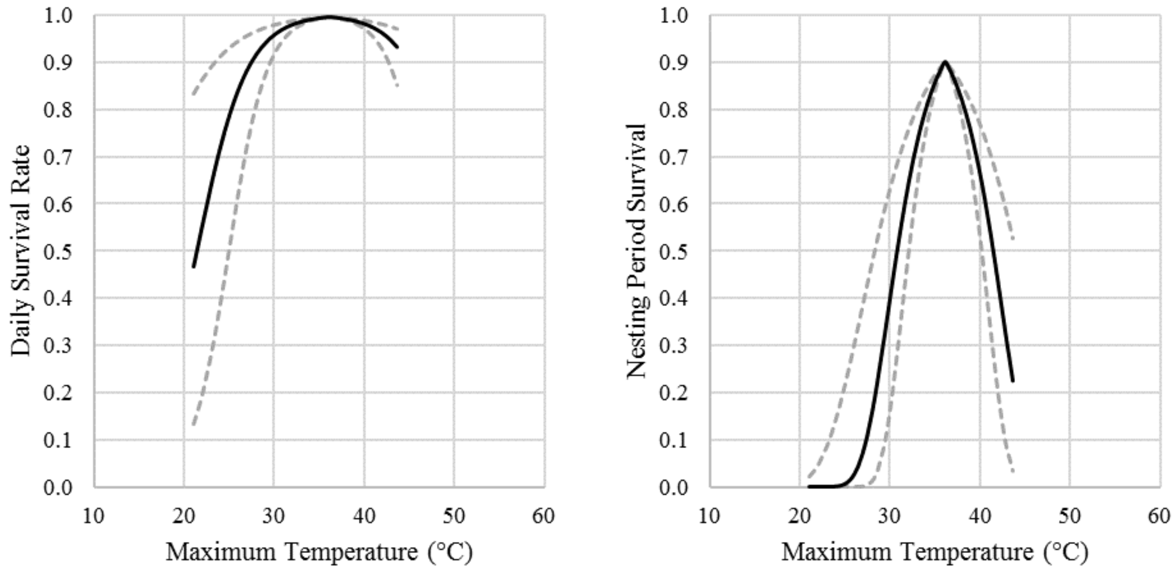

Figure 6. Influence of maximum temperature on predicted daily (DSR; left) and nesting period survival rates (DSR^{28}; right) for piping plover (*Charadrius melodus*) nests with 95% confidence intervals.

Table 10. Top 5 models, as ranked by AICc statistic, that best predict piping plover (*Charadrius melodus*) brood survival. The null model had an ΔAICc value >20.

Model	Parameters	AICc	ΔAICc	weight	Deviance
NS	9	560.81	0.00	0.85	542.78
MinTD + MaxTD + S	4	564.26	3.45	0.15	556.25
MaxTD	2	573.59	12.78	0.00	569.59
MinTD	2	574.81	13.99	0.00	570.80
S	2	576.36	15.55	0.00	572.36

DISCUSSION

A compilation of fifteen years of nesting data at nine managed off-channel sites within the AHR allowed for an extensive investigation into nest and brood survival to identify trends over a longer temporal period than had ever been investigated for the central Platte River. We observed high survival rates for least tern nests and broods as 65% of all nests hatched at least 1 chick and 76% of all broods resulted in at least 1 fledgling. We also observed high survival rates for piping plover nests and broods as 77% of all nests hatched at least 1 chick and 75% of all broods resulted in at least 1 fledgling.

Extreme temperature conditions and weather events can have a great influence on nesting or brooding least terns and piping plovers (Dinan 1982, Krogh and Schweitzer 1999, Schweitzer and Leslie 2000, Harris et al. 2005, Whittier and Leslie 2009). We found high and low temperatures in the AHR influenced least tern nest and brood survival and piping plover nest survival more than any other metric we tested. Eggs can be especially impacted by extreme temperatures due to lack of mobility and embryonic development that is sensitive to temperature conditions (Whitman 1988, Thompson et al. 1997). Similarly, chicks have a limited ability to thermoregulate before fledging thus we found least tern brood survival was also susceptible to changes in temperature (Howell 1959, Krogh and Schweitzer 1999). We did not find a strong effect of temperature on survival of piping plover chicks as survival was primarily related to colony site.

Habitat covariates we evaluated were not found to influence nesting and brood rearing period survival. We found productivity of least terns and piping plovers is being reduced during both the nesting and brood rearing stage by climactic factors that are impossible to mitigate or manage for. This finding indicates current habitat management activities at off-channel sites create conditions that are, at the very least, not negatively impacting nesting and brood rearing period survival of least terns and piping plovers. To date, the Program and its partners implemented management strategies such as providing dry sand areas for nesting during times of high water, removal of woody vegetation ≤60 meters from the nesting areas, constructing water barrier ≥15 meters around nesting areas, and reducing predation through predator trapping and fencing at all sites. If a more experimental system was present, varying management techniques could have been implemented to explore a wider range of values in each covariate and introduce ways to investigate these metrics more directly. However, given our results we conclude management practices implemented to date have decreased threats to least tern and piping plover productivity and increased the overall suitability of nesting habitat in accordance with the Program's species' management plans (Program 2006). As such, we recommend the continuation of current management practices at off-channel sites.

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APPENDICES

Appendix I. Summary statistics for least tern (LETE) and piping plover (PIPL) nest and brood survival analyses.

	Metric	Date First Found	Min Temp (°C)	Max Temp (°C)	Breeding Pair Density (Pairs/hectare)	Elevation (m)	Distance to Predator Perch (m)	Storm Events (#)
LETE/Nest	Average	14 June	10	36	0.45	2.13	170.10	0.02
	SD	12 days	3	2	0.44	1.22	77.90	0.14
LETE/Brood	Average	2 July	12	36	0.53	NA	NA	0.13
	SD	15 days	3	2	0.52	NA	NA	0.46
PIPL/Nest	Average	22 May	4	34	0.13	2.13	171.63	0.09
	SD	18 days	4	3	0.08	2.13	88.55	0.36
PIPL/Brood	Average	15 June	10	36	0.12	NA	NA	0.19
	SD	18 days	3	3	0.08	NA	NA	0.62