PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM (PRRIP -OR- Program)

Extension Science Plan Big Question #9: Evaluating Effectiveness of Predator Management on Piping Plover and Interior Least Tern Fledge Ratios

The Extension Science Plan Big Question #9 directs Program science to evaluate the effectiveness of additional predator management at mitigating losses of piping plover productivity due to predation. **The EDO requests TAC collaboration in the form of a technical working group to provide input on incremental analytical steps to evaluate effectiveness following three years of implementation.** Results of analyses will be used to inform decisions on whether to continue predator management as currently being implemented, adjust the management strategy, or discontinue additional predator management.

The EDO completed an initial analytical step (Analysis 1) to get a general sense of how the data and proposed analytical framework fit together. Methods used and initial results from Analysis 1 are outlined below. A series of incremental evaluations (Analyses 2–5) that further parse out effects of predation, weather, site specific attributes, and annual variability are included in Appendix A for TAC consideration. Finally, we provide a tentative timeline in Appendix B that plots out analytical steps over time to take us into decision-making for the 2025 plover nesting season.

Experimental Design

Program biologists have monitored piping plovers (*Charadrius melodus*; hereafter plover) and interior least terns (*Sternula antillarum athalassos*; hereafter tern) on up to 10 Program-managed OCSW sites using the same standardized monitoring protocol since 2010 (PRRIP 2024). The 10 sites had basic predator management actions implemented including: electrified fences across the peninsula land entrance to the site; fence panel wings extending into the water at the peninsula land entrance; removal of trees ≤492 ft from the site; placement of avian spikes on non-removable perches; and trapping of mammalian predator species (PRRIP 2024). Data collected on a twice monthly basis for each site includes the number of adults and number of nests. Once nesting is established on a site, the site is monitored twice weekly to determine nest fate (successful; failed), hatching dates (if successful), and brood fate, and enumerate the numbers of chicks, fledglings, and adults (PRRIP 2024).

Beginning in 2021, the Program implemented an intensive predator monitoring study on a sample of six of the OCSW sites. Predator monitoring efforts included: quantifying the number of trapped terrestrial mammals along exterior shorelines; weekly surveys of the peninsula shoreline for tracks of potential predators; deployment of remote cameras at fixed points along the shoreline and on the site to document potential predator presence by species; and monitoring of a sample of plover and tern nests using remote cameras. At three of the OCSW sites (Kearney Broadfoot South; Leaman; Newark West; hereafter "treatment" sites), the Program implemented additional predator management actions beginning in 2021 including the use of lights with flashing and/or random patterns to deter potential predators. The Program also established and maintained permanent fences along the interior shoreline of the peninsula at Kearney Broadfoot South and around the water moat at Newark West. Therefore, we had seven OCSW sites as "controls" and three OCSW sites as "treatments" in terms of predator management with three of the "control" sites having the more intensive predator monitoring since 2021.

Analysis 1. Evaluating management effectiveness for improving fledge ratios with a Before-After-Control-Impact (BACI) paired series design.

Data Summary

Plovers

- 10 OCSW sites surveyed between three and 14 years during 2010–2023 for a total of 121 site-years of observations.
- Biologists observed no plover nesting at one site (Follmer-Alda; 2012–2023). Four other sites had no observed plover nesting between one and three years (total of eight site-years).
- The number of plover nests per year at the 10 sites ranged from 0 to 18 nests (mean = 4.9; SE = 0.38; n = 121).
- The number of plover fledges per year at the 10 sites ranged from 0 to 28 fledges (mean = 4.6; SE = 0.52; n = 121).
- Annual plover fledge ratios at the nine sites with nesting ranged from 0 to 4 chicks fledged/nest (mean = 0.998; SE = 0.088; n = 101).

Terns

- 10 OCSW sites surveyed between three and 14 years during 2010–2023 for a total of 121 site-years of observations.
- Biologists observed no tern nesting at one site (Follmer-Alda; 2012–2023). Six other sites had no observed tern nesting between one and seven years (total of 17 site-years).
- The number of tern nests per year at the 10 sites ranged from 0 to 42 nests (mean = 11.8; SE = 1.0; n = 121).
- The number of tern fledges per year at the 10 sites ranged from 0 to 45 fledges (mean = 9.8; SE = 0.98; n = 121).
- Annual tern fledge ratios at the nine sites with nesting ranged from 0 to 2.8 chicks fledged/nest (mean = 0.871; SE = 0.066; n = 92).

The Leaman OCSW Site

- A predator management “treatment” site with deterrent lighting, but no fencing.
- For plovers, a productive site (4 to 11 fledges per year) during 2013–2016. Since 2016 there has been limited nesting (0 to 3 nests per year) and no fledges.
- For terns, a highly used site during 2014–2016 (14 to 42 nests per year), but limited use since 2016. During 2021 and 2023, there was no observed tern nesting at site. During 2022 there were six tern nests, but all failed due to a severe storm (not predator-related failures).
- Conducted analyses with and without the data from Leaman.

Methods

We proposed a before-after-control-impact (BACI) approach for multiple reasons including its usefulness: (1) in evaluating impacts of natural or human-induced perturbations; (2) where management actions cannot be implemented in randomly selected locations; and (3) when there are limitations for replication. A before-after-control-impact paired series (BACIPS) design (Stewart-Oaten et al. 1986) uses paired datasets from before and after a treatment. The paired series design allows treatment impacts to be distinguished from background time effects shared by all sites; allows treatment impacts to be distinguished from background differences between treatment and control sites; and controls for spatial

differences between treatment and control sites such that they do not have to be identical. This approach was appropriate for our study because of the non-random assignment of control and treatment designations to our OCSW sites; lack of true replicates for control and treatment sites (i.e., each site has its own attributes and conditions); and high annual variability in plover and tern use and productivity within and across sites.

Analysis 1 was a straightforward and relatively simple task to complete to determine whether there was a signal for the effect of predator management on fledge ratios. Analysis 1 also provides information on a response variable that has been important as a Program performance metric. However, using fledge ratios as a response variable has potential limitations. First, the fledge ratio is defined as the number of chicks fledged per nest and is influenced by the number of fledglings and number of nests, both of which may be affected differently by predation. Second, use of fledge ratios combines losses of nests and broods from all sources (e.g., predation; weather; abandonment) and does not allow an examination of how losses specifically from predation may have changed following implementation of additional predator management. Third, our ability to assess changes in fledge ratios due to different forms of predator management (i.e., interior fencing; exterior fencing; deterrent lights) with three years of data and only three sites was limited. Further analytical steps are necessary to address these issues.

Analysis 1a. Before-after-control-impact paired series (BACIPS) model (Stewart-Oaten et al. 1986)

- **Response variables:** Annual plover fledge ratios from the six "control" and three "treatment" OCSW sites. Annual tern fledge ratios from the six "control" and three "treatment" OCSW sites.
- **Covariates:** *treatment* (categorical control; treatment); *time* (categorical before treatment; after treatment); *site* (random effect for site ID).
- **Analytical framework:** linear mixed-effects models in program R (Pinheiro and Bates 2000, Pinheiro et al. 2023, R Core Team 2023)
- **Model:** $\text{fledgeratio}_{\text{species,site,year}}$ = *treatment* + *time* + *treatment*time* + *site*. This is considered a classic BACI model.

Analysis 1b. Mean differences (Stewart-Oaten et al. 1986)

- **Response variables:** Mean difference in plover fledge ratios between treatment and control sites after the treatment (2021–2023 period) minus the mean difference between treatment and control sites before the treatment (2010–2020 period). Mean difference in tern fledge ratios between treatment and control sites after the treatment (2021–2023 period) minus the mean difference between treatment and control sites before the treatment (2010–2020 period).
- **Covariate:** *time* (categorical before treatment; after treatment)
- **Analytical framework:** t-test or Mann-Whitney U-test.

Analysis 1c. BACI ratio (Conner et al. 2016)

- **Response variables:** Average annual plover fledge ratios at treatment sites divided by average annual plover fledge ratios at control sites. Average annual tern fledge ratios at treatment sites divided by average annual tern fledge ratios at control sites.
- **Covariate:** *time* (categorical before treatment; after treatment)
- **Analytical framework:** t-test or Mann-Whitney U-test.

Results

Analysis 1a. Plovers—BACIPS model

- No significant difference in plover fledge ratios by *treatment*, *time*, or with *treatment*time* interaction for analyses with or without the data from Leaman.

Analysis 1a. Terns—BACIPS model

- No significant difference in tern fledge ratios by *treatment*, *time*, or with *treatment*time* interaction for analyses with or without the data from Leaman.

Analysis 1b. Plovers—Mean Differences

- No significant difference in mean differences in plover fledge ratios between treatment and control sites after and before the treatment for t-test and U-test with or without the data from Leaman.

Analysis 1b. Terns—Mean Differences

- No significant difference in mean differences in tern fledge ratios between treatment and control sites after and before the treatment for t-test and U-test with or without the data from Leaman.

Analysis 1c. Plovers—BACI Ratio

- No statistically significant difference (at $\alpha = 0.05$) in BACI ratio of plover fledge ratios before and after treatment based on a t-test. However, 95% confidence interval of the difference in means was not centered on 0 (95% CI = -1.20, 0.113) with a mean difference of -0.546 when including data from the Leaman OCSW site (Figure 1a).
- No significant difference in BACI ratio of plover fledge ratios before and after treatment based on a t-test when not including data from the Leaman OCSW site (Figure 1b).

Analysis 1c. Terns—BACI Ratio

- No significant difference in BACI ratio of tern fledge ratios before and after treatment based on a t-test when including data from the Leaman OCSW site (Figure 2a).
- No significant difference in BACI ratio of tern fledge ratios before and after treatment based on a t-test when not including data from the Leaman OCSW site (Figure 2b).

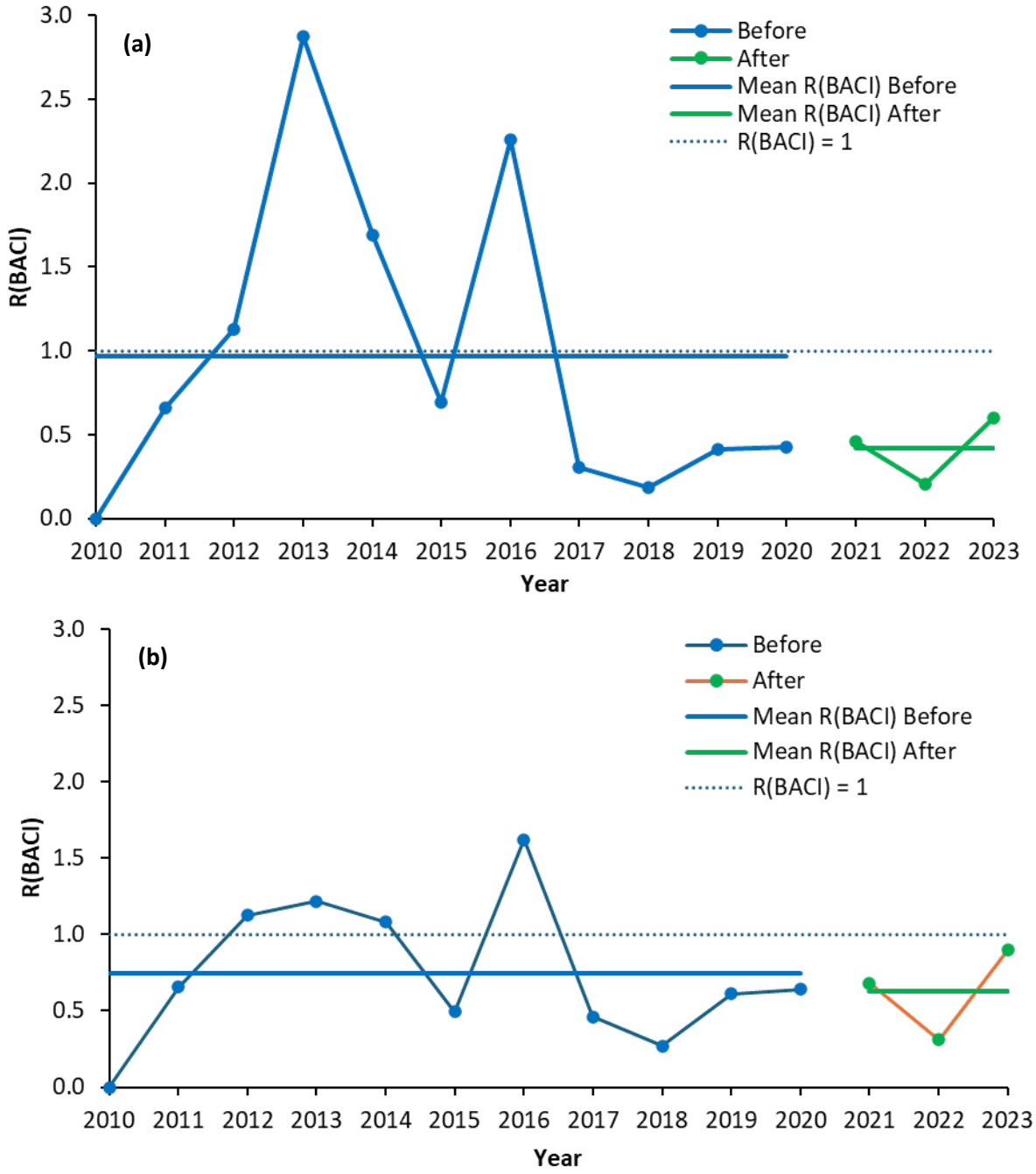

Figure 1. Annual and mean BACI ratios [R(BACI)] for annual plover fledge ratios (chicks fledged/nest) before and after implementation of predator management at three OCSW sites. For (**a**) BACI ratios include fledge ratio data from the Leaman OCSW site. For (**b**) BACI ratios do not include fledge ratio data from the Leaman OCSW site. The annual BACI ratio is defined as the average annual plover fledge ratios at treatment sites divided by average annual plover fledge ratios at control sites.

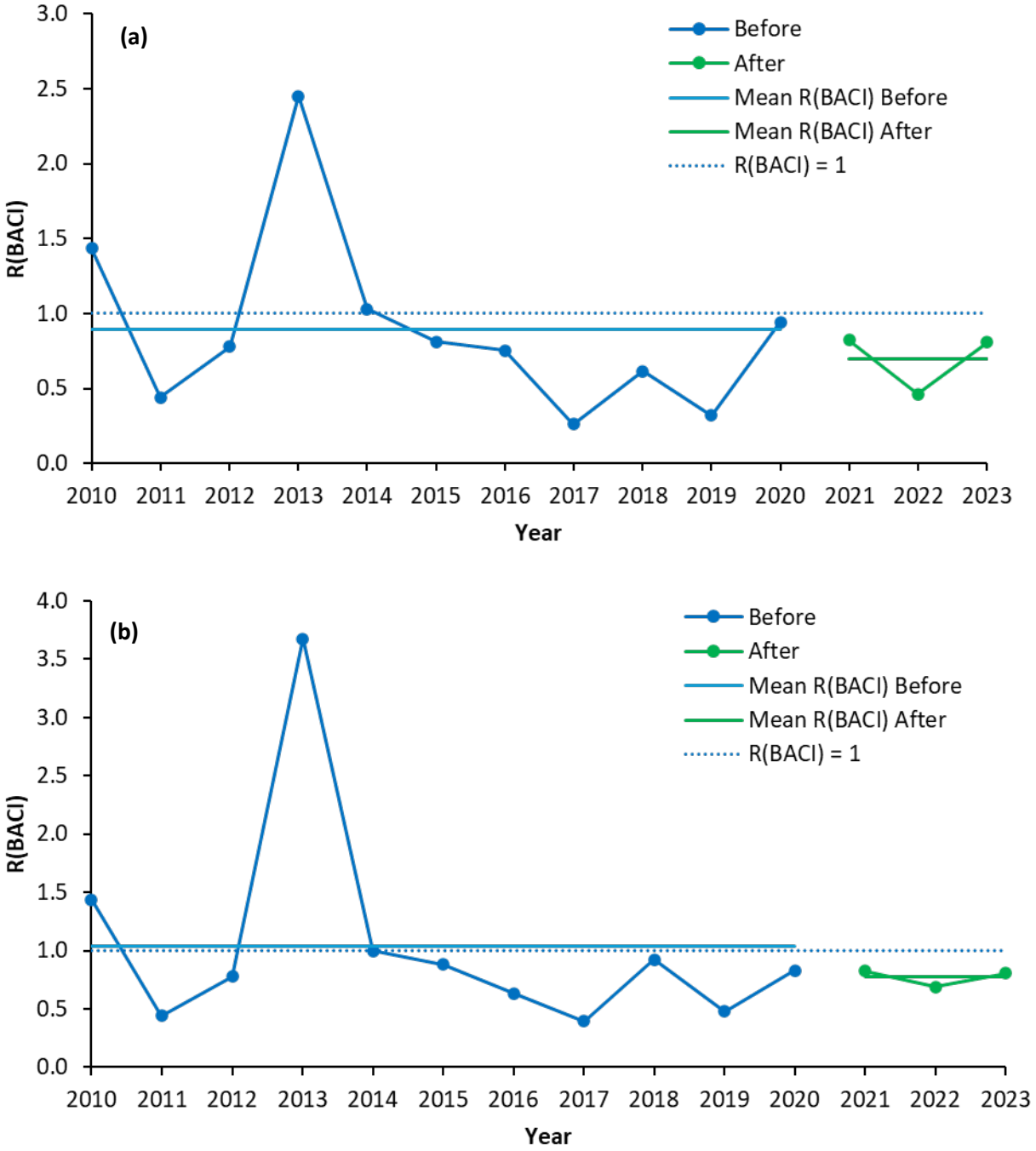

Figure 2. Annual and mean BACI ratios [R(BACI)] for annual tern fledge ratios (chicks fledged/nest) before and after implementation of predator management at three OCSW sites. For (**a**) BACI ratios include fledge ratio data from the Leaman OCSW site. For (**b**) BACI ratios do not include fledge ratio data from the Leaman OCSW site. The annual BACI ratio is defined as the average annual tern fledge ratios at treatment sites divided by average annual tern fledge ratios at control sites.

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APPENDIX A: INCREMENTAL ANALYTICAL STEPS
EVALUATION OF EFFECTIVENESS OF PREDATOR MANAGEMENT

Analysis 2. Quantifying the role of predation on and impact of other factors affecting daily nest and brood survival with a BACI paired series design.

We will use our twice weekly nest and brood monitoring data from the 10 OCSW sites to separately fit models for daily nest survival (*n*) and daily brood survival (*b*) for plovers and terns (Dinsmore et al. 2002, Shaffer 2004).

- **Response variable(s):** Plover daily nest survival rate from the seven "control" and three "treatment" OCSW sites. Plover daily brood survival rate from the seven "control" and three "treatment" OCSW sites. Tern daily nest survival rate from the seven "control" and three "treatment" OCSW sites. Tern daily brood survival rate from the seven "control" and three "treatment" OCSW sites.
    - Observed nest and brood fates can be incorporated into the nest survival model to specifically examine the impact of predation.
- **Covariates:**
    - *Predator management and monitoring factors:* presence of interior fence (yes; no); presence of exterior fence (yes; no); use of deterrent lighting (yes; no); nest monitored by camera (yes; no).
    - *Site and nest attribute factors:* area of potential nesting habitat; age of the OCSW site since construction or rehabilitation; nest initiation date; number of other nests on site.
    - *Random effects:* site; year.
- **Analytical frameworks:** Bayesian multinomial logistic exposure model (Darrah et al. 2018); Bayesian BACI ratio for a BACIPS design (Conner et al. 2016, Dudley et al. 2022); Bayesian Control-Impact assessments (Chevalier et al. 2019).
    - A Bayesian multinomial extension of the logistic exposure nest survival model (Darrah et al. 2018) allows incorporation of: (1) multiple causes of nest loss to assess competing probabilities of nest failure; (2) random effects to account for a lack of independence of fate probabilities within sites; and (3) annual and site-specific covariates.

Analysis 3. Quantifying factors affecting plover abundance, survival, and recruitment, and using a BACI effect to evaluate the effectiveness of predator management on these parameters.

- **Response variable:** annual total number of adult plovers at the seven "control" and three "treatment" OCSW sites.
- **Additional model parameters:** initial abundance; apparent survival; recruitment; detection probability.
- **Covariates:**
    - *For initial abundance*: initial area of potential nesting habitat at site *i*.
    - *For apparent survival and/or recruitment*:
        - Site attributes and previous nesting: area of potential nesting habitat at site *i* in year *t*; age of site *i* since construction or rehabilitation; apparent nest success at the site the previous year; maximum number of breeding pairs at the site the

previous year; number of fledglings at the site the previous year; and maximum and minimum water surface elevation at the site during year *t*.
        - Weather variability: total accumulated precipitation during May through July during year *t*; average maximum and minimum daily temperatures during May, June, and July during year *t*.
        - Temporal: the year for evaluation of different functional forms of a trend.
        - Predator management: presence of interior fence (yes; no); presence of exterior fence (yes; no); use of deterrent lighting (yes; no).
        - BACI: *treatment* (control; treatment); *time* (before treatment; after treatment). We will evaluate a "classic" BACI effect as *treatment* + *time* + *treatment* x *time*.
    - *For detection probability*: Julian date
- **Analytical framework:** *N*-mixture model (Dail and Madsen 2011).

Analysis 4. Assessing predator communities and responses to management through evaluation of predator detections across sites and time with camera trap data.

- **Response variable:** number of unique potential predator registers per total camera effort at three "control" and three "treatment" OCSW sites during 2021–2023.
- **Covariates:** year (2021; 2022; 2023); OCSW site (Cottonwood Ranch; Dyer; Kearney Broadfoot South; Leaman; Newark East; Newark West); use of deterrent lighting; presence of exterior fence; presence of interior fence; camera type (shoreline; site; nest); and group of species types (avian; mammalian; reptilian/amphibian).
- **Analytical framework:** mixed-effects regression.

Analysis 5. Use of a Monte Carlo population projection model to predict impacts of predation on future plover abundance at OCSW sites through variations in adult breeding pairs and fledge ratios.

- **Response variable(s):** annual total number of plover breeding pairs at OCSW sites; annual plover fledge ratio.
- **Covariates:** adult survival; juvenile survival; nesting density, adult immigration and emigration; juvenile immigration and emigration; available nesting habitat; nesting density.
- **Analytical framework:** Markov chain Monte Carlo simulation.

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APPENDIX B: TIMELINE
EVALUATION OF EFFECTIVENESS OF PREDATOR MANAGEMENT

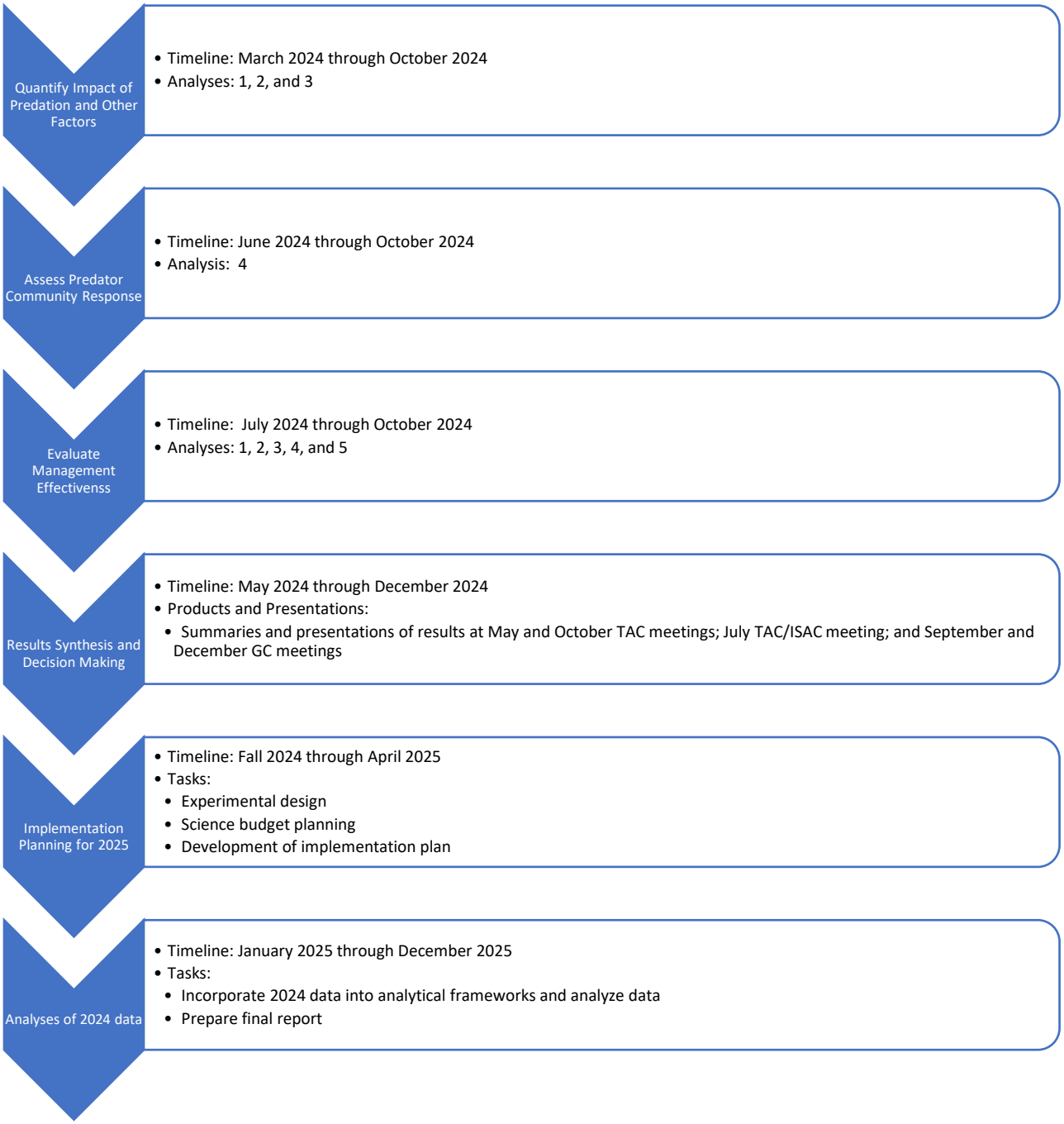

Figure 1. Tasks and associated timelines for data analyses, presentation of results, decision making, and implementation.