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Fish Release Site Predation Monitoring

Tracy Fish Facility Improvement Program
California-Great Basin · Interior Region 10

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14. ABSTRACT
In 2019, the Bureau of Reclamation and California Department of Water Resources conducted a study designed to determine relative predation rates that occurred at Federal and State Sacramento-San Joaquin River Delta fish release sites and what factors contributed to this relative predation rate. Modified tethers with hook timers were baited with Golden Shiners (*Notemigonus crysoleucas*) at a fixed release site and two control sites in the Sacramento-San Joaquin River Delta, California to monitoring predation rates. Modified fish releases were conducted throughout summer and several factors (i.e., predation time, amount of sunlight, water depth, etc.) were analyzed to determine what factors may influence predation rates. Altering the frequency from the standard salvage release every day to every fifth day did not reduce relative predation rates. Exploratory data analysis did find diurnal period and water depth appeared to have the largest influence on relative predation rates at the release site. Predation rates may be decreased at release sites by altering the fish release schedule to crepuscular periods and ensuring deep water releases. These results will help managers better understand relative predation rates at release sites. Further investigation into potential management actions may be needed if predation reduction efforts at release sites do not meet management goals.

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Mission Statements

The U.S. Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated Island Communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Tracy Fish Facility Improvement Program

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Disclaimer

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Acronyms and Abbreviations

ANOVA	Analysis of Variance
BO	Biological Opinion
BPP	Harvey O. Banks Pumping Plant
BRT	Boosted Regression Trees
CDWR	California Department of Water Resources
CLRS	Curtis Landing Release Site
CTRL-A	Control Location A
CTRL-B	Control Location B
CVP	Central Valley Project
Delta	Sacramento-San Joaquin River Delta
JPP	C.W. "Bill" Jones Pumping Plant
MS 1	Management Strategy 1
MS 2	Management Strategy 2
NMFS	National Marine Fisheries Service
RPA	Reasonable and Prudent Alternatives
SCADA	U.S. Bureau of Reclamation Supervisory Control and Data Acquisition
SDFPF	John E. Skinner Delta Fish Protective Facility
SWP	State Water Project
TAF	Tracy Aquaculture Facility
TSLSR	Time Since Last Salvage Release

Executive Summary

Operations at the Bureau of Reclamation (Reclamation) Tracy Fish Collection Facility (TFCF) and the California Department of Water Resources (CDWR) John E. Skinner Delta Fish Protective Facility (SDFPF) are directed to salvage fish from waters destined for Federal and State water export pumping plants. Entrained fishes, including federally protected species, are collected (salvaged) and contained in holding tanks, then trucked daily to four fixed release sites up to 55 km north of the salvage facilities near the confluence of the Sacramento and San Joaquin Rivers. These salvaged fishes released in the Sacramento-San Joaquin River Delta (Delta) likely experience high mortality because of predation by piscivorous fish and birds at or near the fixed release sites (NMFS 2019, Miranda et al. 2010a). The goals of this project were to 1) develop a consistent and reliable tool to measure release site predation rate, and 2) determine a suitable approach to reduce release site predation rates at the release sites.

From 2000 to 2003, TFCF salvaged ~ 35,000 Chinook Salmon (*Oncorhynchus tshawytscha*) annually, some of which were federally protected (winter-run and spring-run; Federal Register 70(123):37160-37204, June 28, 2005). Since that time, annual salvage of Chinook Salmon of all runs has declined to relatively low levels. The National Marine Fisheries Service (NMFS) 2009 Biological Opinion determined long-term operations of the Central Valley Project (CVP) and State Water Project (SWP) adversely affects endangered winter-run and threatened Central Valley spring-run Chinook Salmon and directed Reclamation and the CDWR to take actions to increase Chinook Salmon salvage efficiency and end-of-pipe survival (i.e., release site predation; NMFS 2009). A new Biological Opinion was released in 2019 reiterating the need to reduce relative predation rates of Chinook Salmon and other protected species at release sites (NMFS 2019). Though release site predation has been a concern for decades, common methods such as netting, mark and recapture, stomach analysis, other common fisheries science methods are not easily applicable to end-of-pipe and large open systems such as the Delta. Therefore, losses due to predation at release sites have not been well quantified.

Starting late 2016, an interagency working group convened to address the release site predation problem and worked together to develop possible tools and management/operational solutions. The group has identified variables likely to affect survival of salvaged fish, including frequency of releases, water temperature, and predator abundance, to name a few. Pilot and proof-of-concept phase research efforts have revealed limitations associated with acoustic telemetry studies previously intended to quantify predation rates (Fullard et al. 2019). Field demonstrations and computer simulations, which eliminated acoustic telemetry and netting studies from contention, now point to tethered predation experiments as the key research tool to measure release site predation loss.

In 2019, a study was designed to determine if modifying the frequency of fish releases significantly decreased relative predation rates at release sites. The study objectives were to 1) determine whether tethered fishing could estimate relative predation rates within the vicinity of release and control locations, 2) whether salvage releases every fifth day or more could reduce relative predation rates at the release sites by one half compared to the current management strategy of one salvage release per day at a particular release site, and 3) whether there are other environmental variables at the release site that influence relative predation rates. In addition, several environmental variables (e.g., depth,

solar radiation, habitat type, etc.) were sampled to determine what other outside factors may contribute to predation. This study found that altering the frequency from a salvage release every day to a salvage release every fifth day did not reduce relative predation rates. Exploratory data analysis did find diurnal period and water depth appeared to have the largest influence on relative predation rates at the release site. This suggests altering the fish release schedule so fish-hauls occur during the crepuscular periods and ensuring deep water releases would likely be the most effective management actions for reducing predation rates at the release sites.

Introduction

The Bureau of Reclamation's (Reclamation) Tracy Fish Collection Facility (TFCF) and the California Department of Water Resources' (CDWR) John E. Skinner Delta Fish Protective Facility (SDFPF) remove fish (salvage) from water destined for Federal and State water pumping plants, respectively. Both facilities are in the southern region of the Sacramento-San Joaquin River Delta (Delta). Salvaged fishes, including federally protected species, are removed upstream of the pumping plants, contained in holding tanks, and trucked daily to four fixed release sites up to 55 km north of the salvage facilities near the confluence of the Sacramento and San Joaquin Rivers (Figure 1). Salvaged fishes released in the Delta likely experience high mortality because of predation by piscivorous fish and birds at or near the release sites (Miranda et al. 2010a, Fullard et al. 2019). The goals of this project were to 1) develop a consistent and reliable tool to measure release site predation rates and 2) determine a suitable approach to reduce release site predation rate.

The TFCF and SDFPF typically salvage millions of fish annually, including native, non-native, and State/federally protected fish species, all of which are released at four fixed release sites (Horseshoe Bend, Emmaton, Curtis Landing, Antioch; Figure 1) throughout the year. From 2003 to 2017, TFCF average annual salvage of Chinook Salmon (*Oncorhynchus tshawytscha*), including those that are federally protected (winter and spring runs; Federal Register 70(123):37160-37204 June 28, 2005) was 12,017 fish (range: 106.5 fish in 2015 to 35,294.9 fish in 2006; Figure 2). The National Marine Fisheries Service's (NMFS) 2009 Biological Opinion (BO) determined the long-term State and Federal fish salvage operations may be adversely affecting endangered winter-run and threatened Central Valley spring-run Chinook Salmon.

Quantifying release site relative predation rates of salvaged fish is a driving research question for both State and Federal operations. Survival of salvaged fish at the Delta release sites is likely dependent on several factors including seasonal fish assemblages, diurnal behavior, frequency of site-specific releases (e.g., number of releases per day), tides, river discharge, and total abundance of fish in each release. Miranda et al. (2010a) conducted a release site predation study in 2007–2008, which concluded that predation of salvaged fish does occur at the State and Federal release sites, and that piscivorous fishes tend to remain near the release sites when the number of fish being released is consistently high. Although predation rate was not calculated, this study determined that predation during releases could have a substantial effect on salvaged fish survival.

Salvaged fishes are released from underwater pipes at the release sites. These end-of-pipe areas are usually located in relatively deep, high-flow, and seasonally turbid waters and tend to release fish into a large open water systems, which makes many fisheries monitoring techniques (e.g., netting, biotelemetry) ill-equipped to provide accurate assessments of salvaged fish relative predation rates at a reasonable cost and effort. Concurrently, there have been few attempts to accurately describe the size of the predation area around the release pipes. National Marine Fisheries Service (NMFS, 2009) included a list of Reasonable and Prudent Alternatives (RPAs) regarding fish salvage operations, including a requirement to reduce "end-of-pipe" predation rate by 50%. To address this RPA, an interagency working group convened to design a study of release site predation rates and to estimate release site predation loss (Fullard et al. 2019). This study builds on those pilot and feasibility level research efforts.

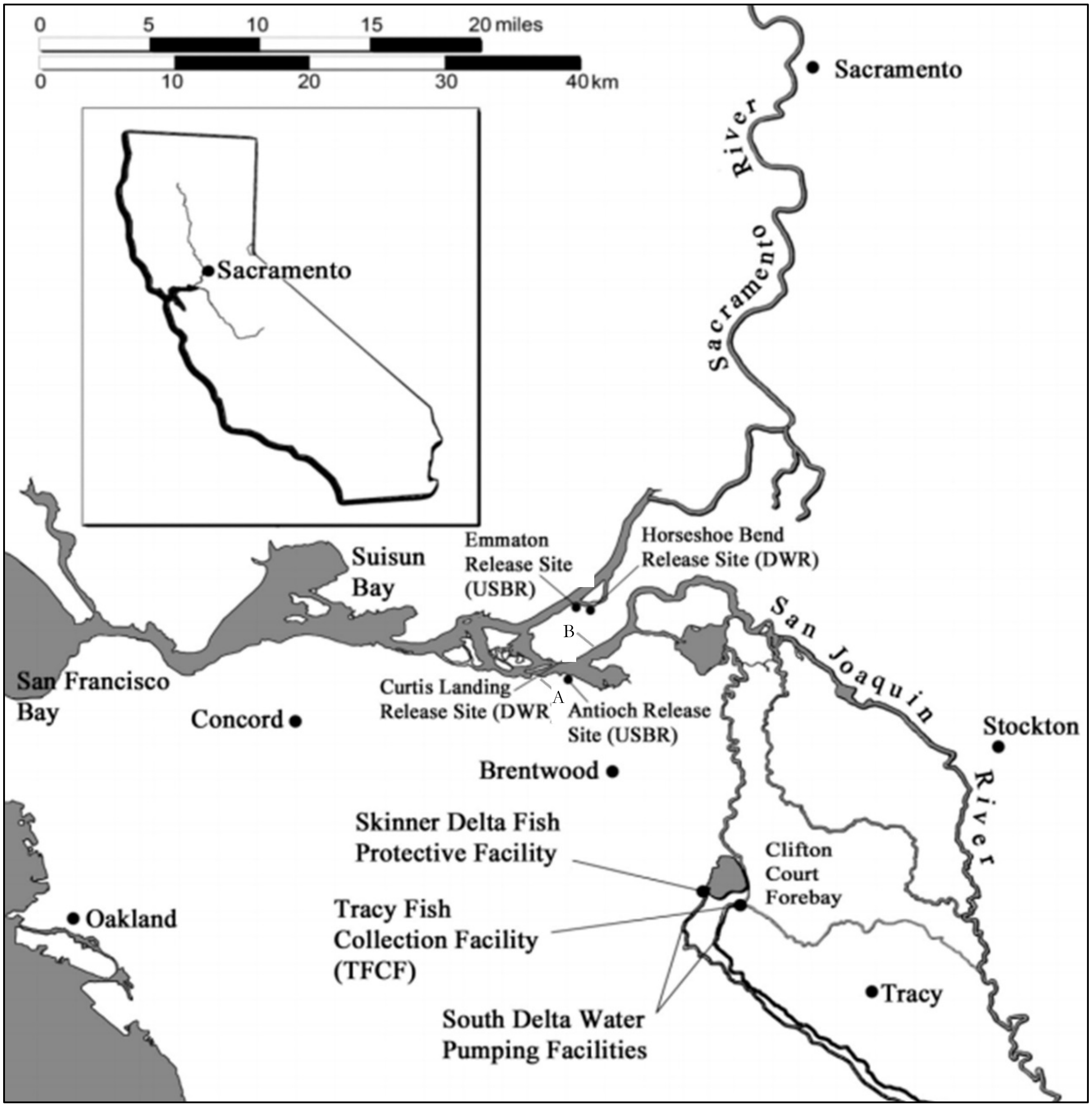

Figure 1.—Map of the Sacramento-San Joaquin River Delta showing the location of the State and Federal pumping facilities (South Delta Water Pumping Facilities), fish salvage facilities (Skinner Delta Fish Protective Facility and Tracy Fish Collection Facility), fixed release sites (Antioch Release Site, Emmaton Release Site, Curtis Landing Release Site and Horseshoe Bend Release Site) and control locations (control location A [A] and control location B [B]) located near the confluence of the Sacramento and San Joaquin Rivers. Curtis Landing Release Site was the treatment site for this study. Figure is from Karp and Bridges (2016).

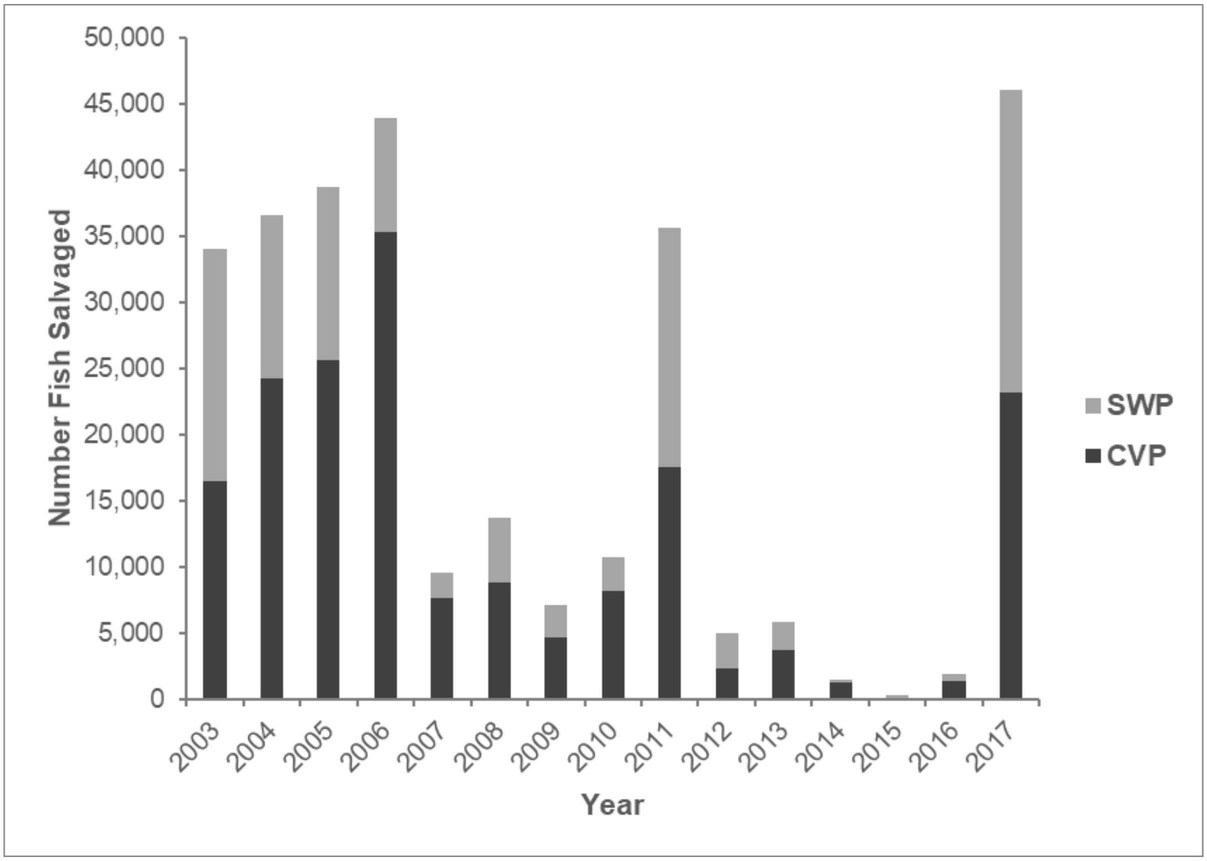

Figure 2.—Graph of total Chinook Salmon (*Oncorhynchus tshawytscha*; all runs and origins combined) salvage per year from 2003 to 2017, showing proportions of fish salvaged at the Tracy Fish Collection Facility (Central Valley Project; CVP) and John E. Skinner Delta Fish Protective Facility (State Water Project; SWP) in the Sacramento-San Joaquin River Delta.

Our objectives were to 1) determine whether tethered fishing could estimate relative predation rates within the vicinity of release and control locations, 2) whether salvage releases every fifth day would be enough to disrupt "daily feedings" to discourage predators from relying on prey at the release sites by one half compared to the current management strategy of one salvage release per day at a particular release site, and 3) whether there are other environmental variables at the release site that influence relative predation rates. By determining the relative predation rates of tethered prey fish over the period of highest numbers of salvage fish being released at the Curtis Landing Release Site (CLRS), we believe our techniques could enable us to provide accurate estimates of release site predation throughout the Delta.

Methods

Sample Site

This project was conducted at one treatment site (CLRS) and two control locations (A and B) within the Delta (Figure 1). Both control locations were chosen because they exhibited similar infrastructure in the water compared to CLRS, were close in proximity to CLRS (< 4.0 km), as well as similar bathymetry to CLRS. For example, CLRT-A had an irrigation pipe located within the site which closely resembled the release site pipe at the treatment site. Tethered fish studies occurred for nine days per month in June, July, August, September, and October 2019. In addition, hydroacoustic surveys were conducted alongside tethering studies (3 days/week, 3 weeks/month, for 3 months). It is thought that predators tend to be more active during this timeframe leading to higher predation rates (Feyrer et al. 2003; Niobriga and Feyrer 2007).

The original sample locations contained ~ 50 tether positions within each sample location. After a power analysis (Bowen, Unpublished Data) was completed on preliminary data it was determined that tether positions could be reduced due to insufficient relative predation rates in the pelagic zone (Kruskal Wallis; $P < 0.05$). The number of tether positions at each sample location was reduced to include only tether positions located in the littoral zone to be able to determine changes in relative predation rates between treatments. In addition, only tethers that did not drift from their original deployment location were included.

Predation Assessment

In May 2019, we tested a modified salvage release regime in which the CLRS ceased releases after pre-treatment monitoring. We continued to monitor relative predation rates with tethers, while also monitoring predator assemblages using hydroacoustics to develop a relationship between time-since-release and relative predation rate, as well as large-target abundance. This monitoring was done at the treatment site and both control sites.

Tethers with hook timers were used to monitor the relative predation rate for the treatment and control sites. The tethers were custom built but resembled commercially available tethers (Demetras et al. 2016) and were constructed with five main considerations:

- Must float vertically in the water column
- Contain a main line
- Contain a hook timer which records the time (seconds) of each predation event
- Must have lightweight (3.63 kg test) monofilament tether loops attaching fish to hook timers
- Utilize a lightweight anchor

Live Golden Shiners (*Notemigonus crysoleucas*; mean = 83.3, range = 49-115) were used as tethered prey due to the abundance and availability of the species. Tethers were attached to prey fish by a snap through the jaw. Hook timers (Figure 3), which are available off-the-shelf for the commercial fishing industry, were adapted for use in the Sacramento-San Joaquin River Delta in 2018. For 2019 efforts, custom-built units were constructed by the Reclamation Technical Service Center Hydropower Diagnostics and Supervisory Control and Data Acquisition (SCADA) Laboratory. The hook timer was situated between the prey fish and the main line of the tether. When predation events occurred, the predator pulled the bait fish which in turn pulls a plunger from the hook timer, which disrupted a magnetic field and activated the timer. The predator then pulls the bait fish from its snap, releasing it from the tethering unit, which is a similar technique tested and used by NMFS (Demetras et al. 2016). One bait fish was tethered to each main line. Each tether was independent and a total of twenty tethers were deployed for each sampling event (site/day). Soak time for each tether was roughly twenty minutes. Twenty tethers were fished at a site for each sampling event and all tethers were stationary sets. Survey boats avoided motoring over the release site or control waters during the daily experiments to reduce disturbance to predators. The location of a tether within a site and bait fish location on the tether (top 1/3, middle, bottom 1/3) were randomly selected. Golden Shiners were stored at the Tracy Aquaculture Facility (TAF).

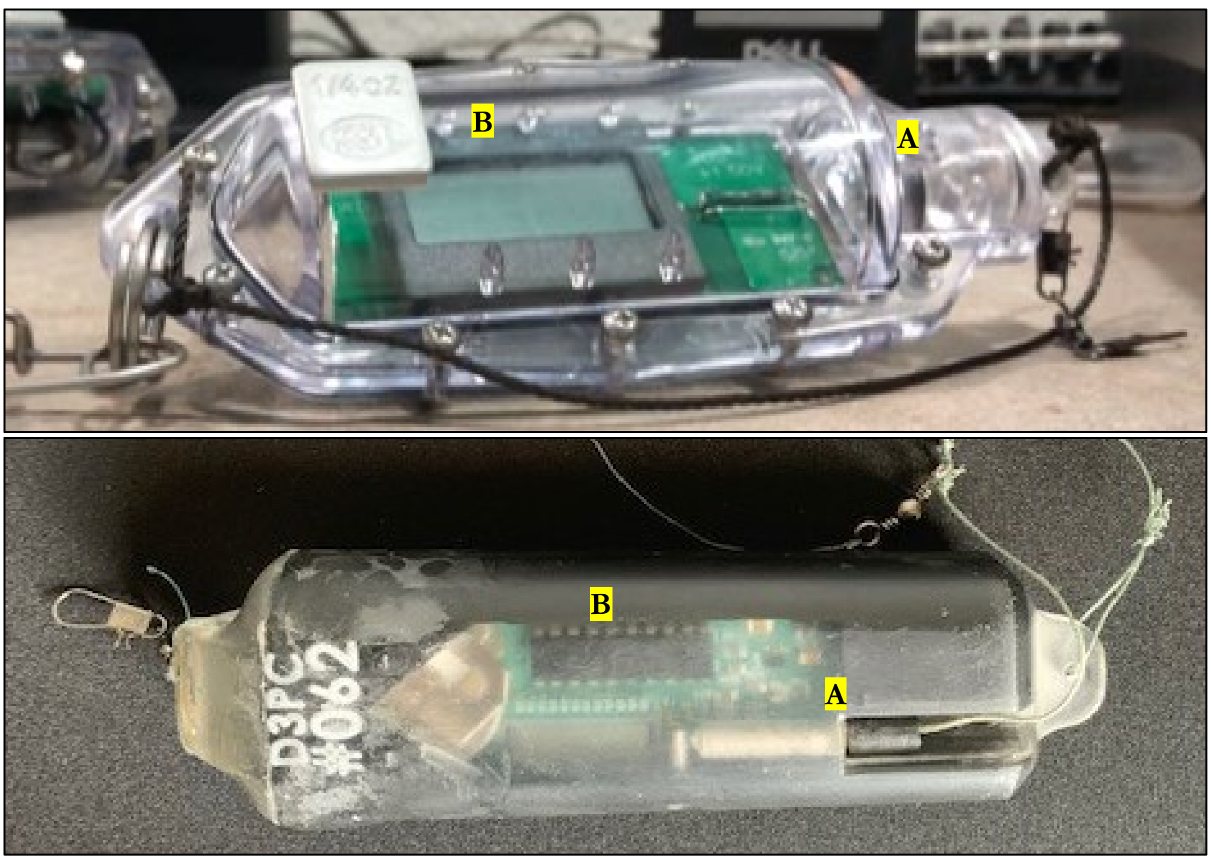

Figure 3.—Lindgren Pitman LP Hook Timer HT-600 (Top) and custom-made hook timer from Bureau of Reclamation (Bottom). The plunger (A) on the right side of the hook timer is held in place by a magnet, which once pulled actives a stopwatch (B) in the body of the hook timer.

A natural or baseline relative predation rate measurement was conducted by performing tethered experiments away from the assumed predator aggregations (Miranda et al. 2010a) at control sites A and B with similar offshore distance and water depths (e.g., 15-50 m offshore and 4.5-7.6 m deep) as the State and Federal release sites. Data was collected simultaneously at the control sites and treatment site. The two control sites were used instead of a single control site (used in 2018 pilot efforts) to increase our ability to capture natural predator density and predation variation across the study reach of the lower San Joaquin River (Fullard et al. 2019). This was intended to help elucidate whether there is a difference in relative predation rates between release sites and control sites that do not have a salvage release in the Delta. Water quality data was monitored from the CDWR Blind Point monitoring station (Station ID 47080; https://data.cnra.ca.gov/dataset/water-quality-data).

Hypothesis Testing

Sample Unit

For hypothesis testing, the experimental unit selected was a 10-hour period between 6:00 a.m. and 4:00 p.m. for day samples and between 6:00 p.m. and 4:00 a.m. for night samples. This sample unit is referred to in the following sections as one sample. This unit of observation was selected to ensure that replicates are independent, thus, meeting one of the key assumptions in the use of parametric statistics.

Dependent Variable and Hypotheses

The dependent variable of interest is relative predation rate:

$$R = A/n \qquad \text{(Eq. 1)}$$

where:
R = relative predation rate,
A = number of prey fish attacked in the sample unit, and
n = number of prey individuals fished on tethers during the sample unit.

Relative predation rate estimates (R) were relative in these datasets because the prey individuals were not free to avoid predation. The method of tethering the prey fish encumbers them and makes them more vulnerable to a predatory attack.

The primary influences on relative predation rate that were evaluated were location, management strategy, and time of day (day vs night). The location null hypothesis was:

$H1_0$: There is no difference in relative predation rate between control and treatment (CLRS) locations.

The Management Strategy hypothesis was assessed only at the treatment site. The question about which management strategy to employ in the future was only relevant to CLRS because no infrastructure to release fish exists at the control locations and, therefore, releases cannot be modified or ceased at these locations. The management strategy null hypothesis was:

$H2_0$: At the treatment location (CLRS), there is no difference in relative predation rate between the management strategies.

The two management strategies compared in this hypothesis test were:

1. Current management strategy provided one or more salvage releases each day (1,440 min) at the treatment location (CLRS). This is referred to as Management Strategy 1 (MS 1).

2. The proposed management strategy provided one salvage release followed by a minimum of four days (5,760 minutes) before the next release. This treatment design was based on information gleaned from a pilot study (Fullard et al. 2019) which indicated that a multi-day release cessation could affect predation of juvenile fish. Waiting four days between releases would provide the maximum number of release break replicates during the summer monitoring period that was agreed on with salvage operations. This is referred to as Management Strategy 2 (MS 2).

$H3_0$: At the treatment location (CLRS), there is no difference in relative predation rate between observations made during the day and night.

The two periods compared in this hypothesis test were:

1. The day observation period was a 10-hour interval between 6:00 a.m. and 4:00 p.m.

2. The night observation period was a 10-hour interval between 6:00 p.m. and 4:00 a.m. (the next calendar day).

Semi-Continuous Experiment Hypothesis

A second approach to the management strategy question was utilized to determine if the cessation of salvage releases led to a reduction in relative predation rate through time. It was theorized that the reduction in relative predation rate, emerging from the cessation of salvage releases, might take longer than four days. Linear regression was used to evaluate the relative predation rate at the treatment location through time after the last salvage release on October 5, 2019. The independent variable was time (days) since the last salvage release and the dependent variable was relative predation rate. The null hypothesis tested was:

$H4_0$: The slope of the regression line is zero.

Statistical Techniques and Assumptions

Data was analyzed using assumptions of Analysis of Variance (ANOVA; Sokal and Rohlf 1995). First, the independence of observations had been insured by the selection of the sample unit, one 10-hr period (see Sample Unit section above). Second, the Shapiro-Wilk Normality Test (Shapiro and Wilk 1965) was applied to determine if the data fit a normal distribution. Third, the Bartlett Test of Homogeneity of Variance was used to determine if the different groups had similar variances (Zar 1996). If the Bartlett Test of Homogeneity were violated, then no comparisons were made.

If all three of the assumptions of ANOVA were met, then an unbalanced ANOVA was executed for each dataset. If any of the assumptions were violated, then a non-parametric equivalent of ANOVA was utilized: Kruskal-Wallis Test (Sokal and Rohlf 1995). A critical Type I error rate (α) of 0.05 was used for hypothesis discrimination.

For the test of Hypothesis $H4_0$, the assumptions of linear regression were (NCRM 2011): 1) linear relationship between dependent and independent variables, 2) there is homogeneity of variance (i.e., homoscedasticity) in the dataset, and 3) errors are independent. To assess the first assumption, a visual inspection of a scatterplot of time since last salvage release vs. relative predation rate was conducted to identify if a linear relationship existed or could exist. To assess the second assumption, the Breusch-Pagan Test was executed (Breusch and Pagan 1979; Hebbali 2018). To assess the third assumption, the Durbin-Watson Test was utilized (Durbin and Watson 1950; Zeileis and Hothorn 2002). Then a linear regression was performed on the data and an ANOVA table was constructed to determine if the regression coefficients were equal to zero thus allowing a direct test of hypothesis $H4_0$.

Boosted Regression Tree Analysis

Boosted Regression Trees

Boosted Regression Trees (BRT) combine regression trees, which iteratively split the response data based on a single predictor variable such that the between-group variance is maximized. The BRT approach is valuable for data exploration because it can illuminate complex relationships that may not have been otherwise explored, and it also produces estimates of the relative importance of each predictor variable. Boosted Regression Tree analysis was conducted using the stepwise approach described in Elith et al. (2008) to identify the optimal number of trees given a learning rate (0.003 for this analysis) and tree complexity utilizing the 'step.gbm' function provided in the R package 'dismo'. Bag fraction was set to 0.5 for all models.

Importance rankings were generated for each individual factor. These importance rankings do not provide any information about the actual form of the relationship between predictor and response. Partial dependence plots were generated for the top factors to show the relationship of a single predictor when all others are held at their mean (for continuous variables) or reference (for factors) values. Location is hypothesized to be a primary determinant of predation, therefore we created separate plots showing the control locations and CLRS for each predictor.

Boosted Regression Tree Cox Proportional Hazards Model

The Cox proportional-hazards model predicts time-to-event in response to a set of covariates. This analysis should be able to provide additional insight into predation risk by analyzing not only if a fish was attacked, but also how long it survived. The Cox model was fit using a BRT framework with the 'gbm' function in the R package 'gbm' by specifying the distribution as 'coxph'. The same predictor variables were used as in the binomial BRT models, except for soak time which forms a part of the time-to-event response variable. The response variable is composed of two values: vulnerability, which is the amount of time an individual was susceptible to predation (time to predation for attacked fish for which the hook timer was activated and soak time for non-attacked fish and attacked fish where the hook timer failed to start) and the binary 'attacked' value. The Cox distribution accounts for the fact that time-to-attack for non-attacked fish is unknown, but greater than their soak time.

Results

Location Hypothesis

Day Observations Only

The baseline values of relative predation rate were obtained on September 26, 2019, (45.0%), September 27, 2020, (21.1%), and September 30, 2019, (40.9%). The mean of these three observations was 35.7% and this mean was used as a baseline for the current relative predation rate under current management actions. A total of 2,855 tethers were deployed throughout the duration of this project. For all comparison tests, normality was tested for all datasets and if normality was achieved (Shapiro-Wilk Normality Test; $P > 0.05$) an ANOVA was used to test for significance. If normality was not reached (Shapiro-Wilk Normality Test; $P \leq 0.05$) then a Kruskal Wallis test was used to determine for significant testing.

The relative predation rate at Control Location A (CTRL-A) was not significantly different than Control Location B (CTRL-B; Kruskal-Wallis; Chi-square = 0.00, df = 1; P = 0.95) allowing for that data to be pooled (Figure 4). The relative predation rate at the pooled control locations was less than CLRS relative predation rate (Kruskal-Wallis; Chi-square = 38.00, df = 1, $P < 0.01$; Figure 4).

Night Observations Only

The relative predation rate observations during night for CTRL-A was not significantly different from the relative predation rate for CTRL-B (ANOVA; F = 2.66, df = 1, P = 0.13; Figure 5), therefore, the control data was pooled for comparisons to CLRS. Using only observations obtained at night, the relative predation rate at the pooled control locations was not significantly different from CLRS observations (Kruskal-Wallis; Chi-square = 0.36, df = 1, P = 0.55; Figure 5).

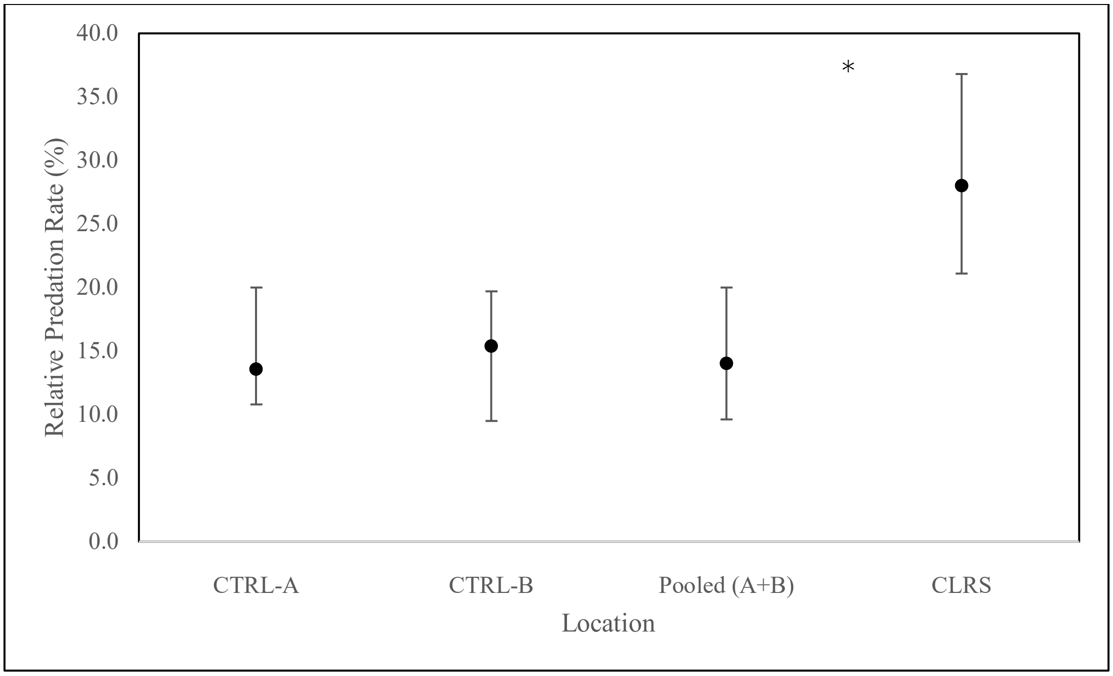

Figure 4.—The graphical representation of the relative predation rate (R) observed during the day in 2019. Filled black circles represent the median and error bars indicate 25th and 75th quantiles. Comparison tests were only conducted between Pooled and Curtis Landing Release Site (CLRS) data. A significant difference (*) was found between pooled control locations and CLRS (Kruskal-Wallis; Chi-squared = 38.00, df = 1, $P < 0.01$).

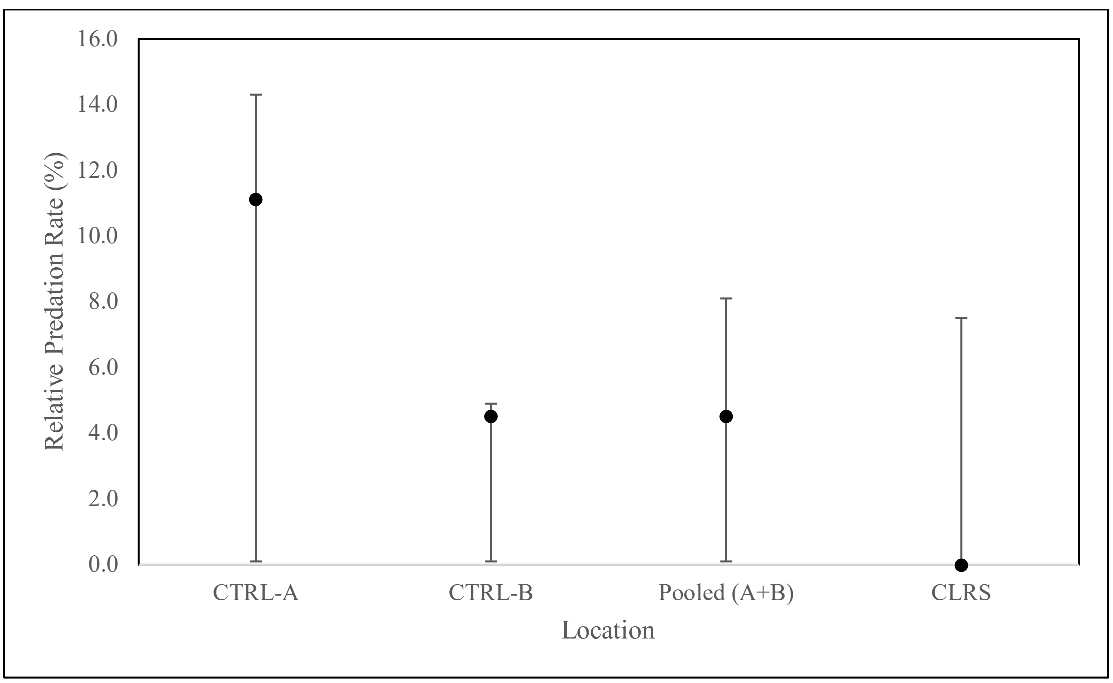

Figure 5.—The graphical representation of the relative predation rate (R) observed during the night in 2019. Filled black circles represent the median and error bars indicate 25th and 75th quantiles. No significant differences were found between Pooled and Curtis Landing Release Site data (Kruskal-Wallis; Chi-square = 0.36, df = 1, P = 0.55).

Management Strategy Hypothesis

Day Observations Only at Control Location A

In day observations at CTRL-A, the relative predation rate for MS 1, one salvage release per day, was not significantly different from the relative predation rate for MS 2, one salvage release every fifth day (Kruskal-Wallis; Chi-square = 0.64, df = 1, P = 0.42; Figure 6).

Day Observations Only at Control Location B

In day observations at CTRL-B, the relative predation rate for MS 1, one salvage release per day, was not significantly different from the relative predation rate for MS 2, one salvage release every fifth day (Kruskal-Wallis; Chi-square = 0.13, df = 1, P = 0.72; Figure 7).

Day Observations Only at Control Location A and B Pooled

In day observations when control location data is pooled, the relative predation rate for MS 1, one salvage release per day, was not significantly different from the relative predation rate for MS 2, one salvage release every fifth day (Kruskal-Wallis; Chi-square = 0.12, df = 1, P = 0.73; Figure 8).

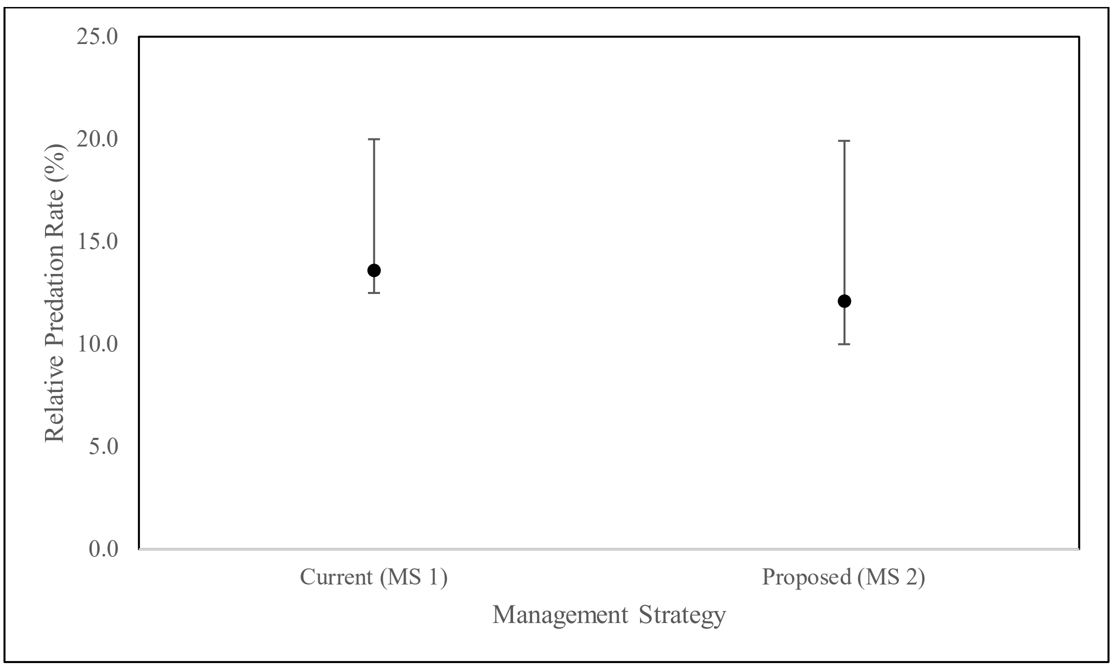

Figure 6.—The graphical representation of the day relative predation rate (R) at Control Location A under two management strategies: Management Strategy 1 – one salvage release per day or Management Strategy 2 – one salvage release every fifth day. Time is the time since the last salvage release occurred. Filled black circles represent the median and error bars indicate 25th and 75th quantiles. No significant differences were found (Kruskal-Wallis; Chi-square = 0.64, df = 1, P = 0.42).

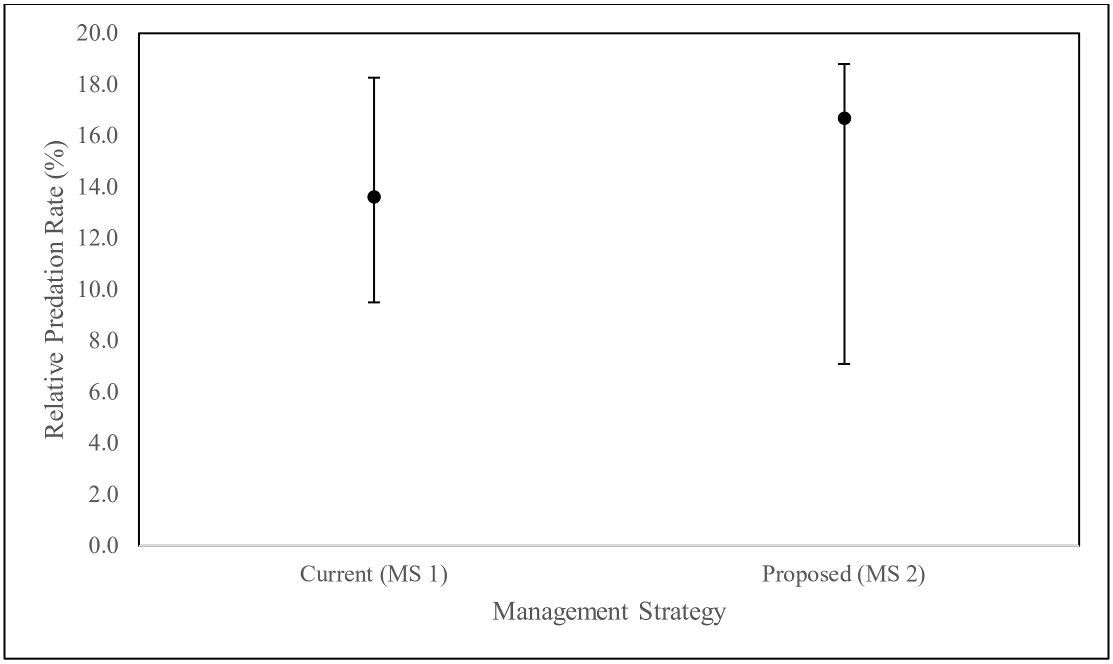

Figure 7.—The graphical representation of the day relative predation rate (R) at Control Location B under two management strategies: Management Strategy 1 – one salvage release per day or Management Strategy 2 – one salvage release every fifth day. Filled black circles represent the median and error bars indicate 25th and 75th quantiles. No significant differences were found between management strategies (Kruskal-Wallis; Chi-squared = 0.13, d.f. = 1, P = 0.72).

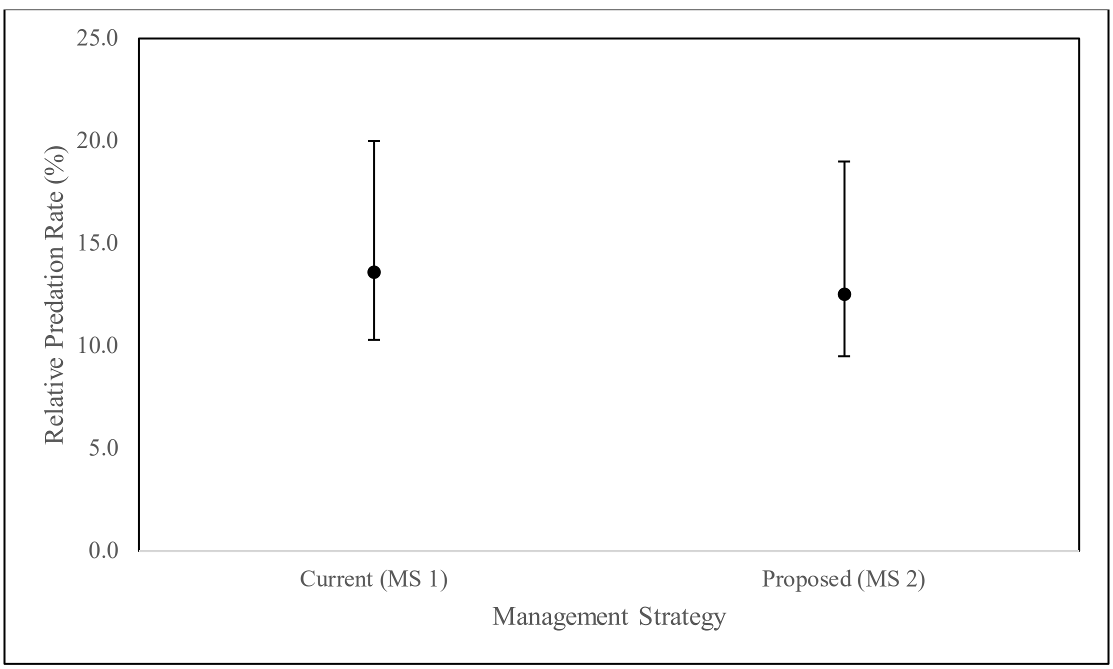

Figure 8.—The graphical representation of the day relative predation rate (R) at Control Location A and B pooled under two management strategies: Management Strategy 1 – one salvage release per day or Management Strategy 2 – one salvage release every fifth day. Filled black circles represent the median and error bars indicate 25th and 75th quantiles. No significant differences were found between management strategies (Kruskal-Wallis; Chi-square = 0.12, df = 1, P = 0.73).

Day Observations Only at Treatment Location CLRS

The relative predation rate for MS 1, one salvage release per day, was not significantly different from the relative predation rate for MS 2, one salvage release every fifth day (ANOVA; F = 0.32, df = 1, P = 0.57; Figure 9) when looking at day sampling events at CLRS.

Night Observations Only at Treatment Location CLRS

Night observations at CLRS found that the relative predation rate for MS 1, one salvage release per day, was not significantly different from the relative predation rate for MS 2, one salvage release every fifth day (Kruskal-Wallis; Chi-square = 0.07, df = 1, P = 0.79; Figure 10). Sample sizes were small with six sampling events on MS 1 and four sampling events on MS 2.

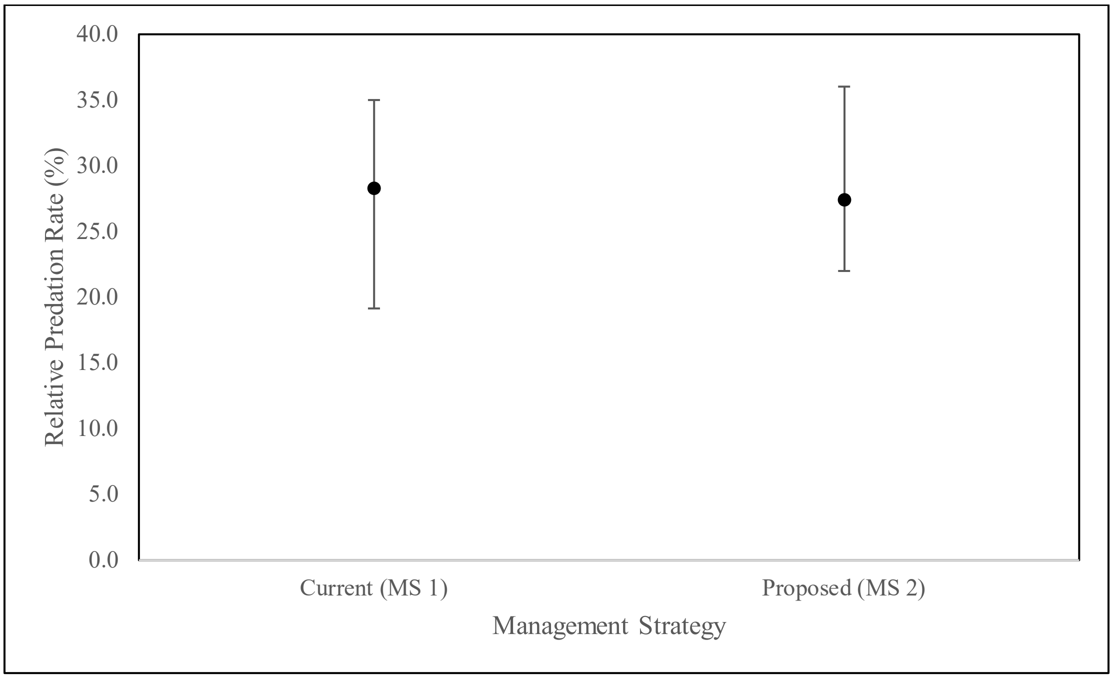

Figure 9.—The graphical representation of the day relative predation rate (R) at the Treatment Location, CLRS, under two management strategies: Management Strategy 1 – one salvage release per day or Management Strategy 2 – one salvage release every fifth day. Filled black circles represent the median and error bars indicate 25th and 75th quantiles. No significant differences were found between management strategies (ANOVA; F = 0.32, df = 1, P = 0.57).

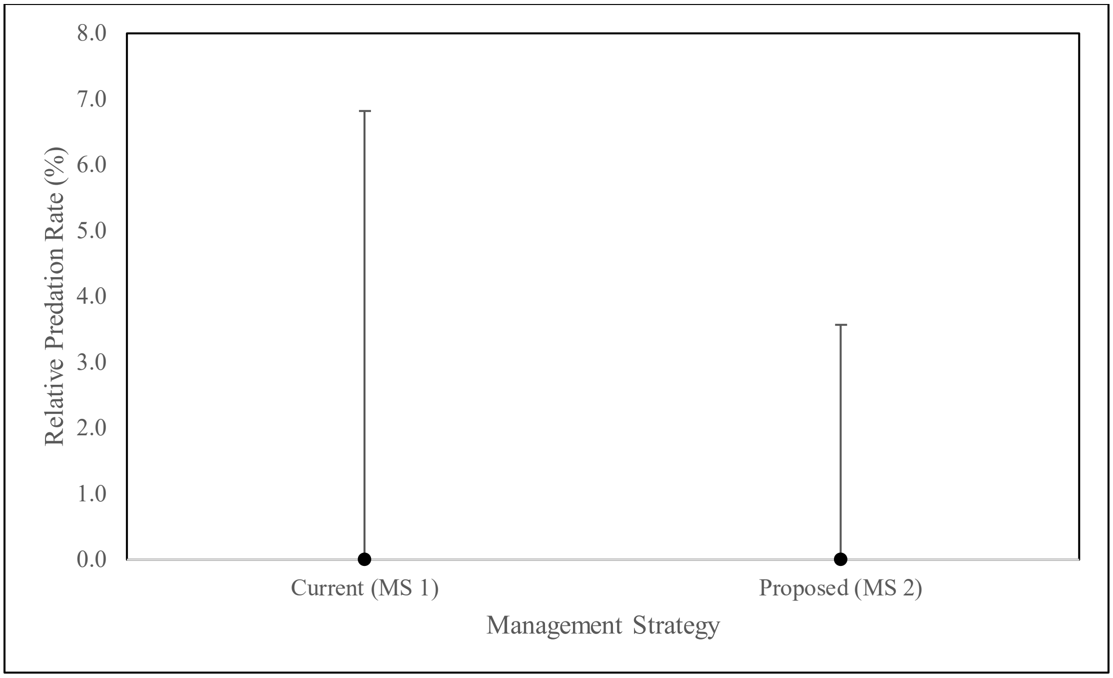

Figure 10.—The graphical representation of the night relative predation rate (R) at the Treatment Location, CLRS, under two management strategies: Management Strategy 1 – one salvage release per day or Management Strategy 2 – one salvage release every fifth day. Filled black circles represent the median and error bars indicate 25th and 75th quantiles. No significant differences were found between management strategies (Kruskal-Wallis; Chi-square = 0.07, df = 1, P = 0.79).

Time of Day Hypothesis

Control Location A Observations Only

When looking at CTRL-A, the relative predation rate during the day was not significantly different from the relative predation rate for the night observations (Kruskal-Wallis; Chi-square = 2.25, df = 1, P = 0.13; Figure 11). Sample sizes were small and imbalanced with five sampling events at night and 40 sampling events during the day.

Control Location B Observations Only

At CTRL-B, the relative predation rate during the day was significantly different from the relative predation rate at night (Kruskal-Wallis; Chi-squared = 13.11, d.f. = 1, P < 0.01; Figure 12). Sample sizes were small and imbalanced with five sampling events at night and 42 sampling events during the day.

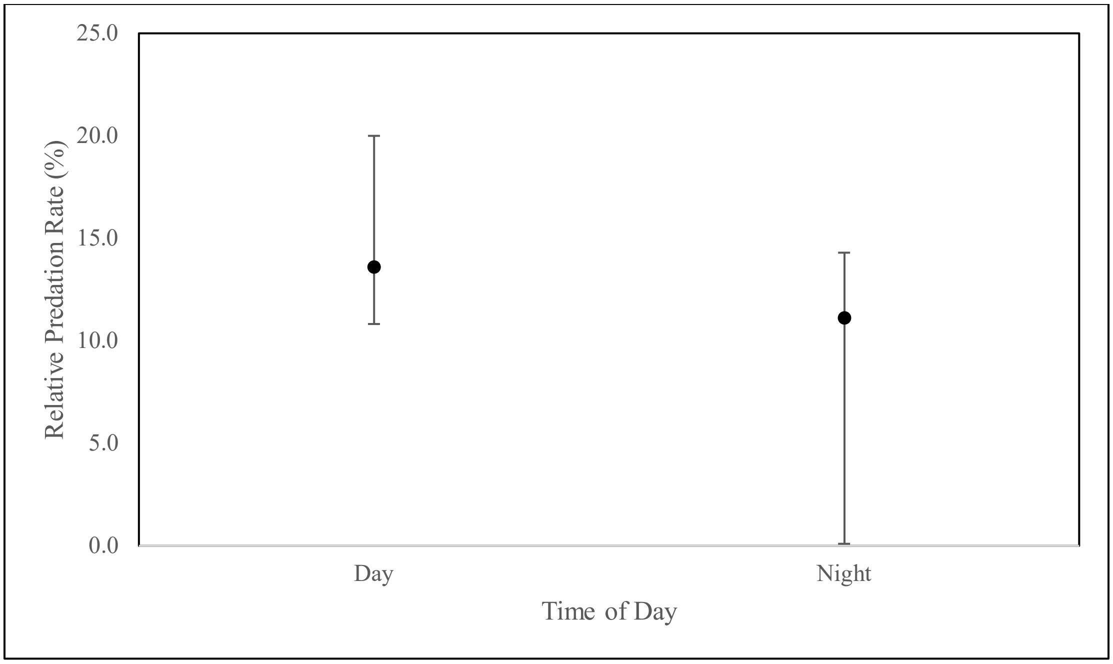

Figure 11.—The relative predation rate (R) at the Control Location A observed during the day and at night. Filled black circles represent the median and error bars indicate 25th and 75th quantiles. No significant differences were found between day and night (Kruskal-Wallis; Chi-square = 2.25, df = 1, P = 0.13).

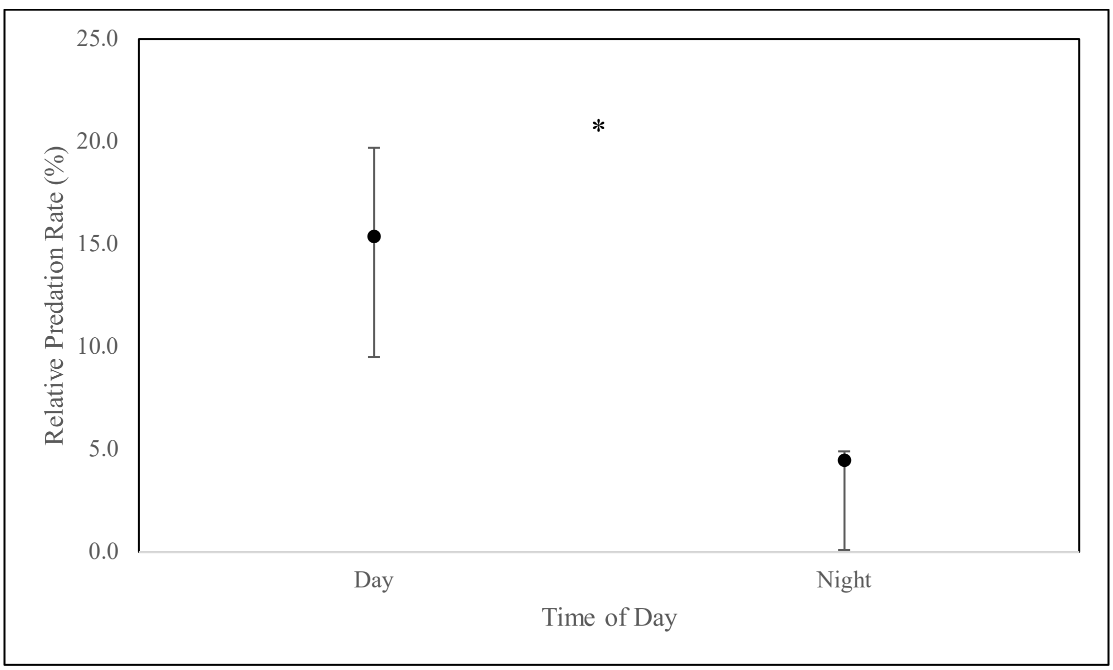

Figure 12.—The relative predation rate (R) at the Control Location B observed during the day and at night. Filled black circles represent the median and error bars indicate 25th and 75th quantiles. A significant difference (*) was found between day and night relative predation rates (Kruskal-Wallis; Chi-squared = 13.11, df = 1, P < 0.01).

CLRS Observations Only

At CLRS, the relative predation rate during the day was significantly different from the relative predation rate for the night observations (Kruskal-Wallis; Chi-square = 18.64, df = 1, P < 0.01; Figure 13). Sample sizes were small and imbalanced with 11 sampling events made at night and 63 sampling events during the day.

CLRS Only, Management Strategy 1 Observations Only

At CLRS, during MS 1, the relative predation rate during the day was significantly different from the relative predation rate for the night sampling events (Kruskal-Wallis; Chi-square = 7.07, df = 1, P < 0.01; Figure 14).

CLRS Only, Management Strategy 2 Observations Only

At CLRS, during MS 2, the relative predation rate during the day was significantly different from the relative predation rate for the night sampling events (Kruskal-Wallis, Chi-square = 8.41, df = 1, P < 0.01; Figure 15).

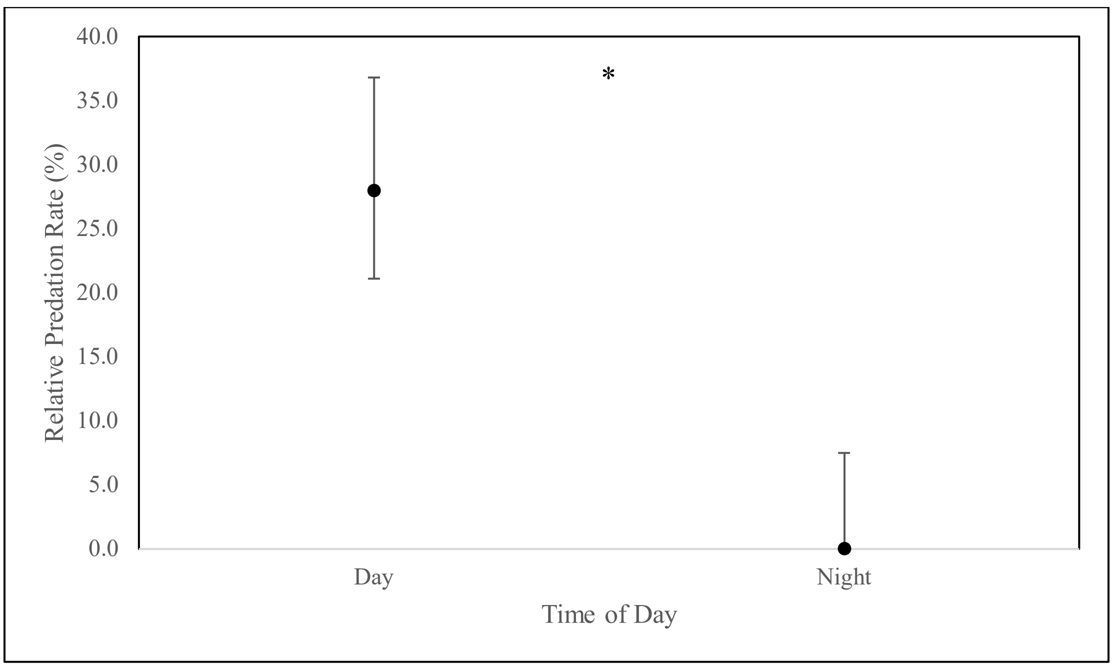

Figure 13.—The relative predation rate (R) at Curtis Landing Release Site observed during the day and at night. Filled black circles represent the median and error bars indicate 25th and 75th quantiles. A significant difference (*) was found between day and night (Kruskal-Wallis; Chi-square = 18.64, df = 1, P < 0.01).

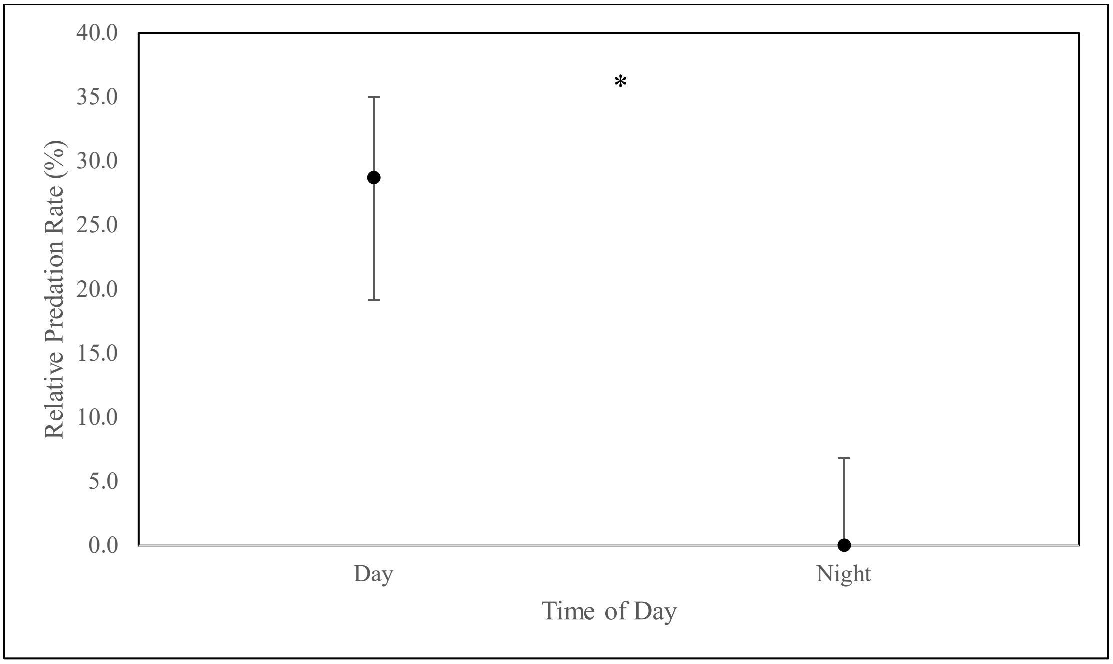

Figure 14.—The graphical representation of the relative predation rate (R) at Curtis Landing Release Site under Management Strategy 1. Management Strategy 1 is the current management strategy of one salvage release per day. Filled black circles represent the median and error bars indicate 25th and 75th quantiles. A significant difference (*) was found between day and night (Kruskal-Wallis; Chi-square = 7.07, df = 1, $P < 0.01$).

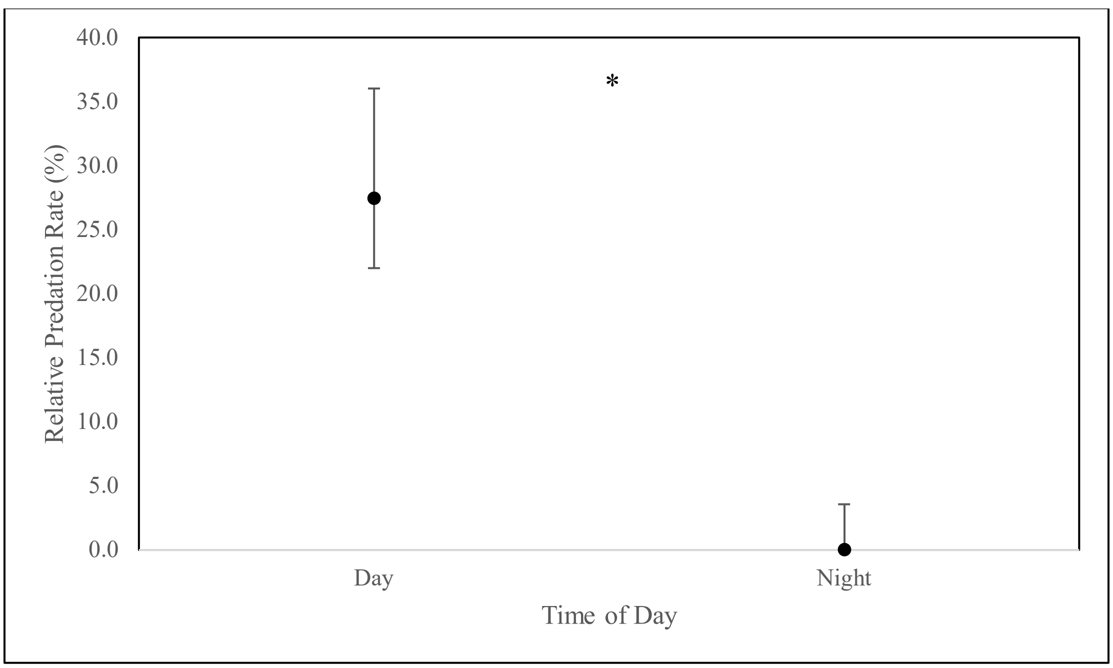

Figure 15.—The graphical representation of the relative predation rate (R) at the Treatment Location, Curtis Landing Release Site, under Management Strategy 2. Management Strategy 2 is the proposed management strategy (one salvage release every fifth day). Filled black circles represent the median and error bars indicate 25th and 75th quantiles. A significant difference (*) was found between day and night (Kruskal-Wallis, Chi-square = 8.41, df = 1, $P < 0.01$).

Semi-Continuous Experiment

On October 5, 2019, the last salvage release was made and there was a 15-day break between salvage releases. During those 15 days, a relative predation rate was determined at random times in a semi-continuous basis to determine relative predation rate over time.

There was no statistically significant reduction in relative predation rate through time after the cessation of salvage releases ($r = -0.01$; linear regression, $t = -0.44$, $P = 0.69$, Figure 16). The adjusted R-squared ($R_{adjusted} = -0.25$) was determined to be negligible.

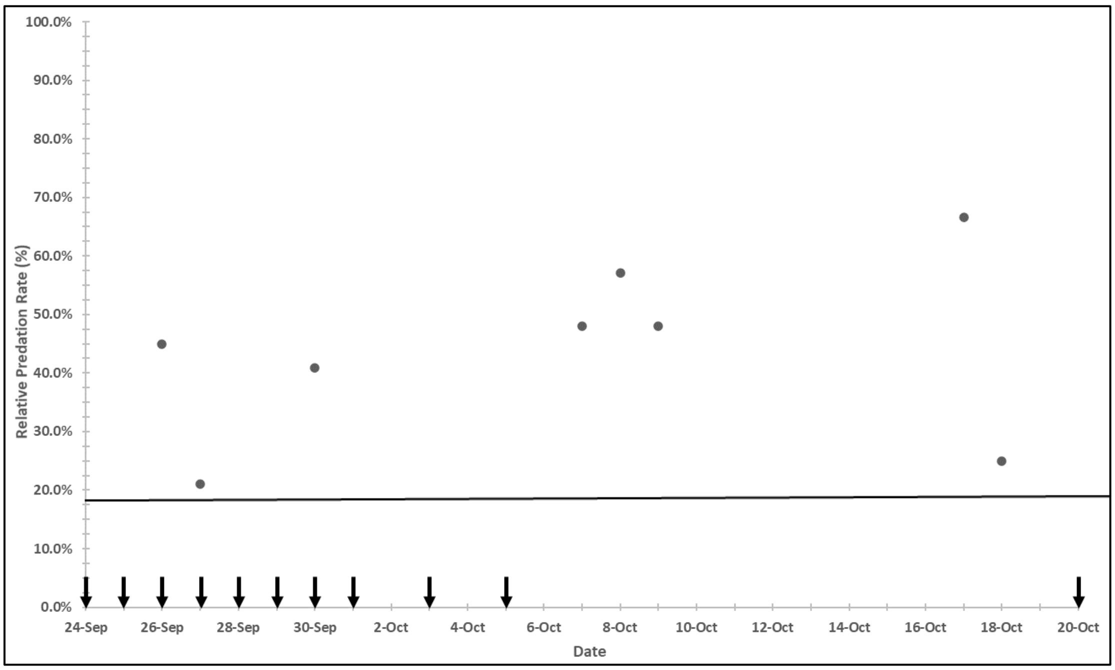

Figure 16.—Relative predation rate on tethered Golden Shiner (*Notemigonus crysoleucas*) adults in 2019 at Curtis Landing Release Site. Black arrows indicate dates on which one or more salvage releases were made at this location. Black line indicates 17.83% which is a reduction by ½ of the mean of R on three dates, (26-Sep, 27-Sep, and 30-Sep), the last three dates before salvage releases ended.

Boosted Regression Trees

Data Preparation

The dataset used for Boosted Regression trees included 2,830 unique observations after removal of outliers. Several variables of both numeric and categorical origin were considered within this dataset (Table 1; Table 3). A second, daytime dataset (N = 1,009) was tested to determine whether any environmental variable influenced relative predation rates during the day. To evaluate the sensitivity of the BRT model to a small number of low TSLSR values (TSLSR < 10) a second dataset consisting of only observations containing TSLSR > 10 was tested (N = 2,800).

To be consistent with the suggestion of Elith et al. (2008) that tree number be greater than 1,000, the model tuning parameters learning rate, tree complexity and bag fraction were adjusted to 0.003, 6 and 0.5, respectively, for the full dataset and TSLSR > 10 trimmed data. Learning rate was decreased to 0.002 for the BRT fitted to the daytime CLRS data subset. Ten-fold cross validation indicated a receiver operating characteristic area under the curve (AUC) scores of 0.762, 0.763 and 0.755, respectively, for the three data subsets, each of which indicates fair predictive ability (Greenwood 2017). Correlation between observed and predicted values was ~ 0.42.

Variable importance scores show the proportion of overall explained deviance that was accounted for by an individual variable. Although highly correlated variables can impact the rankings, and exact ordering can vary slightly because of the stochastic nature of the BRT method, these scores nevertheless provide valuable information about which predictors most strongly influence the response variable. The BRT results show the rankings and relative importance of all predictor variables in the BRT fit to the full data (Table 1) subset and daytime CLRS data subset (Table 2). There was virtually no change in variable importance with the TSLSR > 10 trimmed data subset and so the results are not shown.

The BRT with the full daytime dataset found that the top five factors of importance equated to 59% of the overall importance (Table 1; Appendix A). The most important factor was water depth (16%), with decreasing relative predation rate as water depth increased. The next two most important factors were solar radiation (12%) and distance from shore (12%; Table 1). Relative predation rates increased as solar radiation increased while relative predation rates decreased as distance from shore increased. The fourth most important factor was distance from the release structure (11%). As distance from the releases site structure increased the relative predation rate decreased. The fifth most important factor was water temperature (8%), which demonstrated that relative predation rates decreased in cooler waters. All partial dependence graphs indicating direction of influence on relative predation rate are in appendix A.

Table 1.—Rankings of variable importance based on Boosted Regression Tree analysis: full dataset. Environmental factors measured during field collection or post field work through Google Earth Pro (Google earth Pro V 7.3.2.5776. (2019), California Department of Water Resources Blind Point monitoring station, and the California Irrigation Management Information System.

Rank	Description	Importance
1	Water Depth (m)	16%
2	Solar Radiation (Langley/day)	12%
3	Distance from Shore (m)	12%
4	Distance from Release Site Structure (m)	11%
5	Water Temperature (°C)	8%
6	Distance to Cover (m)	4%
7	Location	4%
8	Prey Size (mm)	4%
9	Habitat Type	3%
10	Soak Time (min)	3%
11	Time Since Last Salvage Release (min)	3%
12	Tether Length (cm)	3%
13	Tide rate of change (min)	3%
14	Tether position	2%
15	Wind Speed (m/s)	2%
16	log(Prey <100mm CPUE)	2%
17	Turbidity (NTU)	2%
18	Tide rate of change^2	2%
19	Salvage release last 24 hrs.	1%
20	Salvage release last 72 hrs.	1%
21	Salvage release last 48 hrs.	1%

The BRT with the TSLSR > 10 trimmed data subset found that the top five factors of importance equated to 56% of the overall importance (Table 2; Appendix A). The most important factor was distance from release site structure (24%) with decreasing relative predation rate as distance from release site structure increased. Water depth (14%) was determined to be the next most important factor. Relative predation rates decreased with increased water depth. This was followed by distance from shore (7%), water temperature (6%), and solar radiation (5%). Relative predation rates decreased when distance from shore increased, water temperature decreased, and solar radiation decreased. All partial dependence graphs indicating direction of influence on relative predation rate are in appendix A.

Table 2.—Rankings of variable importance based on Boosted Regression Tree analysis: daytime, Curtis Landing Release Site. Environmental factors measured during field collection or post field work through Google Earth Pro (Google earth Pro V 7.3.2.5776. (2019), California Department of Water Resources Blind Point monitoring station, and the California Irrigation Management Information System.

Rank	Description	Importance
1	Distance from Release Site Structure (m)	24%
2	Water Depth (m)	14%
3	Distance from Shore (m)	7%
4	Water Temperature (°C)	6%
5	Solar Radiation (Langley/day)	5%
6	Habitat Type	4%
7	Time Since Last Salvage Release (min)	4%
8	Tide rate of change (min)	4%
9	Prey Size (mm)	4%
10	Soak Time (min)	4%
11	log(Prey <100mm CPUE)	4%
12	Turbidity (NTU)	3%
13	Salvage release last 24 hrs.	2%
14	Wind Speed (m/s)	2%
15	Tether position	2%
16	Tide rate of change^2	2%
17	Salvage release last 72 hrs.	2%
18	Tether Length (mm)	2%
19	Salvage release last 48 hrs.	2%
20	Distance to Cover (m)	1%

Cox Proportional-Hazards Model

The Cox proportional-hazards BRT model produced results were qualitatively similar, in terms of both variable importance ranking and partial dependencies, as the binomial BRT models. The Cox proportional-hazards BRT model with the full data varied slightly in importance variables compared to binomial BRT models. The Cox proportional-hazards BRT model found that the top five factors of importance equated to 51% of the overall importance (Table 3; Appendix A). The most important factor was distance from shore (19%), with decreased relative predation rate as distance from shore increased. Water depth (13%) was the next most important factor with relative predation rates decreasing with increased water depth. This was followed by water temperature (7%), with decreasing relative predation rate as temperature decreased. Habitat type (6%) was also an important factor for determining relative predation rate. Habitats with the lowest relative predation rate were vegetation (completely surrounded [360^0] by vegetation within 1m), open water (vegetation or structures > 1m) structure (anthropogenic structure < 1m), vegetation edge (vegetation < 1m not surrounding [< 360^0] sample) and finally riprap (concrete structures on bank

< 1m), respectively. Solar radiation (6%) was the fifth most important factor and relative predation rates decreased when solar radiation decreased. All partial dependence graphs indicating direction of influence on relative predation rate are in appendix A.

The model was fit with 2,000 trees, a learning rate of 0.001, a tree complexity of 4, a bag fraction of 0.5, a training fraction of 0.5, 5-fold cross validation and a minimum node size of 10. All other arguments were left at their defaults. Due to hook timers only activating on less than 40% of attacked fish, time to predation was systematically overestimated, and so model results should be interpreted with caution.

Table 3.—Rankings of variable importance based on Cox proportional-hazards Boosted Regression Tree model. Environmental factors measured during field collection or post field work through Google Earth Pro (Google Earth Pro V 7.3.2.5776. (2019), California Department of Water Resources Blind Point monitoring station, and the California Irrigation Management Information System.

Rank	Description	Importance
1	Distance from Shore	19%
2	Water Depth (m)	13%
3	Water Temperature (°C)	7%
4	Habitat Type	6%
5	Solar Radiation	6%
6	Time Since Last Salvage Release	5%
7	Distance from Release Site Structure	5%
8	Turbidity	4%
9	Tether Length	4%
10	Distance to Cover	4%
11	Location	4%
12	log(Prey <100mm CPUE)	4%
13	Tide rate of change	4%
14	Tide rate of change^2	3%
15	Wind Speed (m/s)	2%
16	Prey Size (mm)	3%
17	Tether position	2%
18	Salvage release last 24 hrs.	2%
19	Salvage release last 48 hrs.	1%
20	Salvage release last 72 hrs.	1%

Discussion

Release site predation has been a concern for Reclamation's TFCF and CDWR's SDFPF and thought to be a major factor contributing to the loss of salvaged fishes released into the Delta (NMFS 2019, Miranda et al. 2010a). Due to these losses at the release sites, NMFS tasked these export facilities with reducing predation by 50% (NMFS 2009). This task was later modified to have the export facilities show significant reduction in predation rate at these release sites (NMFS 2019). It was concluded that the use of tethered fish could be an appropriate tool to establish relative predation rate within the release site region. Using these tethers allowed us to determine release site predation rates for a release site and control sites within the Delta. Hook timers associated with these types of tethers yielded mixed results. Nearly 60% of the hook timers used did not activate when the tethered fish was predated upon. Determining what caused the low activation is difficult. It is possible the magnet used to activate the timer was too strong to pull. Additionally, overtime, grime would build up within the magnet area causing the magnet to stick making it more difficult to activate. Further refinement of the hook timers is needed if these timers are to be used in the future.

Even though a 50% reduction rate in predation at release sites was not achieved through increased time elapsed between releases, an overall significant reduction may be established through modification of management techniques. Miranda et al. (2010a) determined that high predator concentrations at the release site likely contributed to higher predation rates of salvaged fish during the day compared to natural predation within the Delta. We found that release sites, under current management practice of one release each day, did have a higher predation rate compared to control locations. Predators could be attracted to these release sites and in high abundance due to the large amounts of prey fish released by the facilities. A change in management strategy from one salvage release each day to one salvage release every fifth day did not result in a decrease in relative predation rates at the release site. Due to a small sample size for this study and limited release sites available to use for this study, it is hard to determine whether a longer break between salvages would deter more predators and reduce predator abundance. The semi-continuous pilot study did look at long-term predation rates after a release and found that predate rate did not decrease over time.

This further supports the idea that predators are not leaving the release site area. Furthermore, using a more random release schedule has shown little evidence in decreasing predation rates (personal communication, Dan Odenweller). A full understanding of which predator species are abundant around releases sites could help determine what management actions may be successful. Predator species vary between resident (i.e., Sacramento Pike Minnow *Ptychocheilus grandis,* Largemouth Bass *Micropterus salmoides*) and migrant (i.e., Striped Bass *Morone saxatilis*). If predator species are more residential to those areas, then removals of those residents may help to decrease predation rates. If predator species experience more migrant behaviors, then focusing on random release site salvaging or timing around migration periods may be enough to reduce predation rates at release sites. It could also be possible that the release site provides the most beneficial habitat for predators and prey in that region. If this is true, it is likely these fish species would be concentrated at the release site throughout the year, whether salvage releases are conducted there or in other regions of the Delta. Reducing habitat structures that attract predator species may help reduce resident predator species near release sites.

Exploratory analysis revealed that other factors could contribute to changes in relative predation rate within the Delta. Solar radiation, distance from shore, water depth, and water temperature were all key factors in determining the relative predation rate at sample sites in the Delta. Decreases in solar radiation appear to lead to a lower predation rate. Brightness and contrast can have significant effects on the ability of predators to successfully capture prey (Olla and Davis 1990; Clark et al. 2003). Releasing potential prey species at night or in lower solar radiation periods may lower predation at the sight and increase the potential of survival of salvage fish (Roberts et al. 2009). Distance from shore and water depth are both environmental factors that could conceal prey from predation (Sass et al. 2006). Predators could use the shoreline habitat area to conceal themselves for ambush. Releasing salvaged fish deeper and further from the shoreline could result in increased survival due to increased likelihood of predator avoidance. Water temperature is a common environmental factor that influence metabolisms of fish (Hoar and Randall 2014). As water temperature increases, metabolism and predator activity increases leading to higher predation. The opposite occurs when water temperatures decrease leading to lower predation.

Limitations did exist in this study. There was only one species of bait fished used in this study. Although Golden Shiner are a common fish found in the Delta and salvage releases it may not fully represent predation for all species salvaged (i.e., salmonid, smelt). There could be higher and lower rates of predation on specific species during specific times of the year that were beyond the scope of this project. Additionally, it was difficult to find exact control sites within the Delta that could be used for comparisons to the release site. Although the two control sites present were determined to be the best available, differences did exist and should be understood. Habitats (i.e., depths, littoral zones complexity, tidal influences) did vary among sites and could have influenced predation at some level. Even with these differences in habitats it was determined that they were minimal enough to be accurate measures for control sites. This study did it's best to maintain standardization among all these sites to limit these differences. Additionally, predation rates between the two control sites were similar providing confidence they were representative of Delta habitats where release sites were not present.

Recommendations

Management of any export and salvage facility requires the most effective, efficient solutions to solve complex obstacles. Results from this study have shown the relative predation rates (35.7%) at the release site were not reduced by altering the timing of release events. This was further reiterated through the semi-continuous experiment which showed that relative predation rates did not decrease through time after a release was made. Although this project was only conducted over one sampling season, it did support the suggestion that altering releases over time will not lower predation rates and therefore will not reach the goal to reduce the predation rate by 50%.

The exploratory data analysis did provide potential future avenues for meeting the objective of a reduced predation rate at the release site. Releasing further from shore, in deeper water, could help reduce predation rates. Additionally, timing releases around cooler temperatures and avoiding daytime releases may help reduce predation at the release site. A project focused around solar radiation influences on predation with larger sample sizes could provide more information on whether a management action could provide lower predation rates at the release site. Additionally, pros and cons need to be considered. Releasing at night could cause inherent safety concerns with operating fish transportation and releases in the darkness. Furthermore, this would require more employees to be available for evening/night fish transportation and release. Finally, releasing further from shore produces at least three potential problems identified in previous release site studies (Miranda et al. 2010a and 2010b): 1) a longer pipeline could create more physical trauma due to higher contact rate with a longer pipe and additional hydraulic forces, 2) a longer pipeline will be more difficult to fully expel all salvaged-released fish from the pipe, and 3) increased underwater infrastructure to support a longer pipeline could result in velocity refugia and additional predator ambush sites.

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Appendix A—Partial Dependency Plots

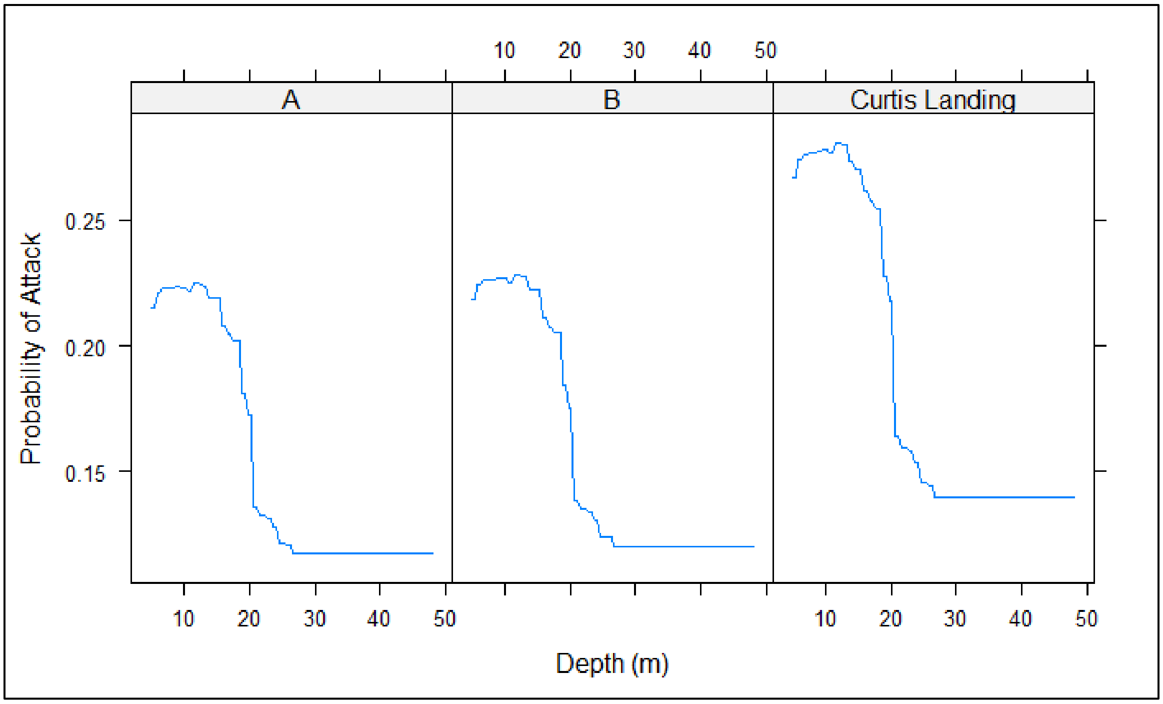

Figure A-1.—Partial dependence of attack probability on water depth across sampling locations.

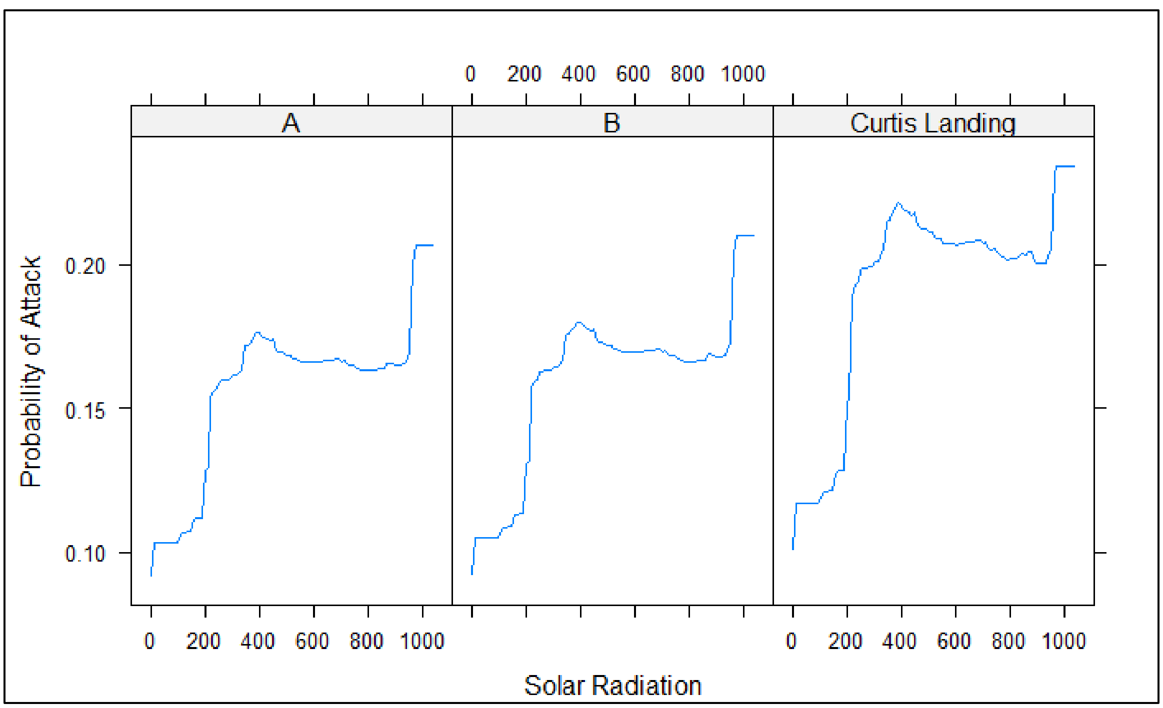

Figure A-2.—Partial dependence of attack probability on solar radiation across sampling locations.

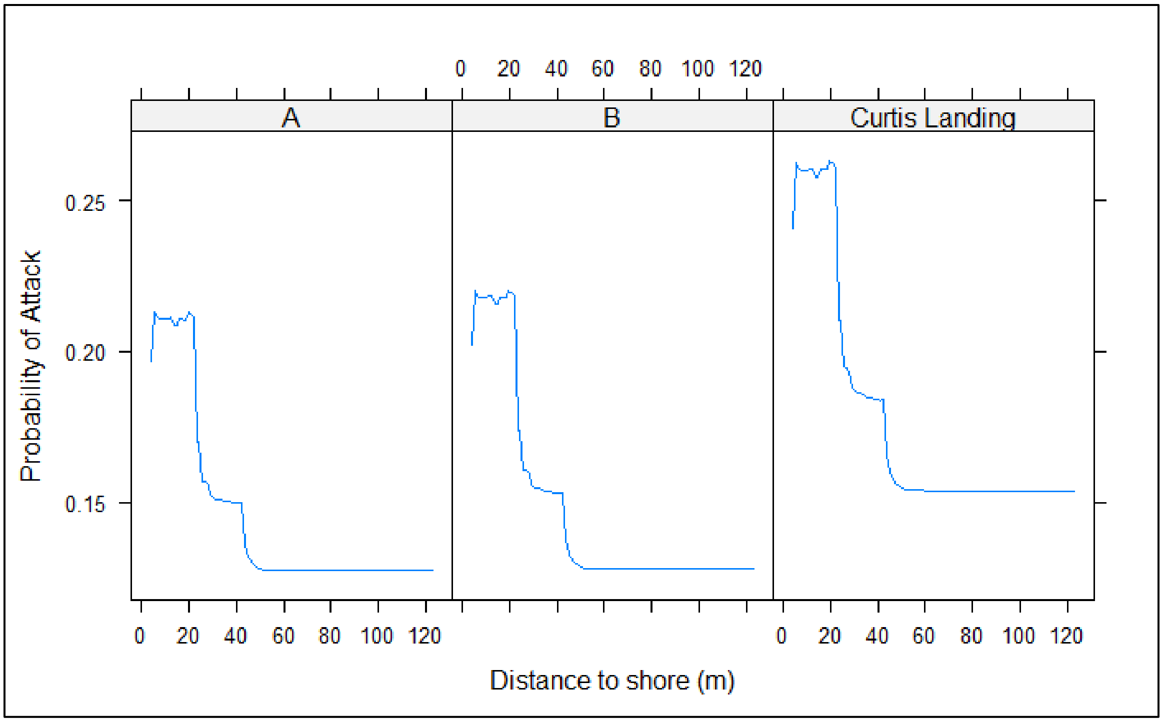

Figure A-3.—Partial dependence of attack probability on distance to shore across sampling locations.

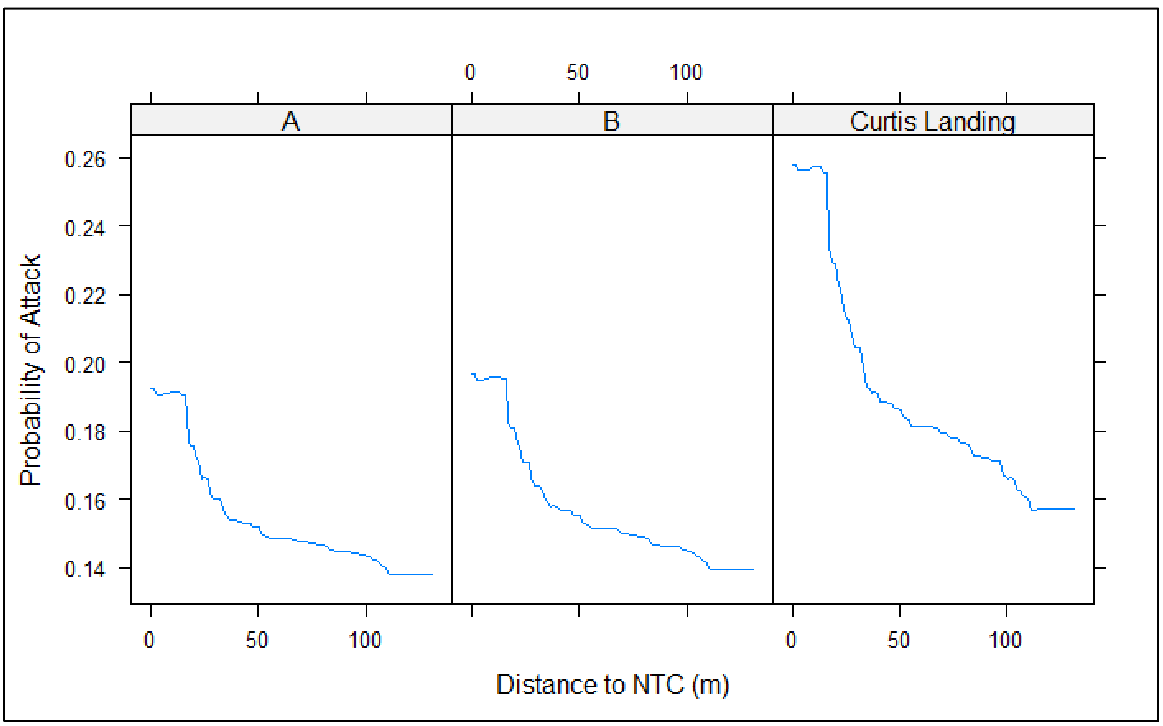

Figure A-4.—Partial dependence of attack probability on distance to center point across sampling locations.

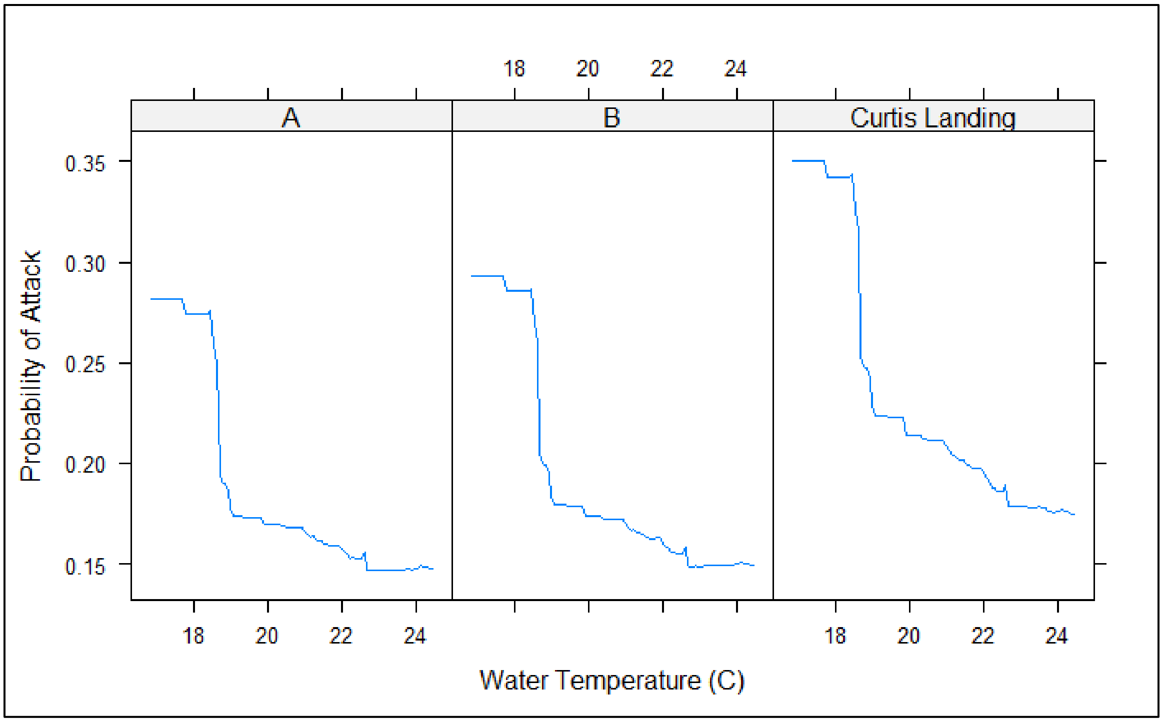

Figure A-5.—Partial dependence of attack probability on water temperature across sampling locations.

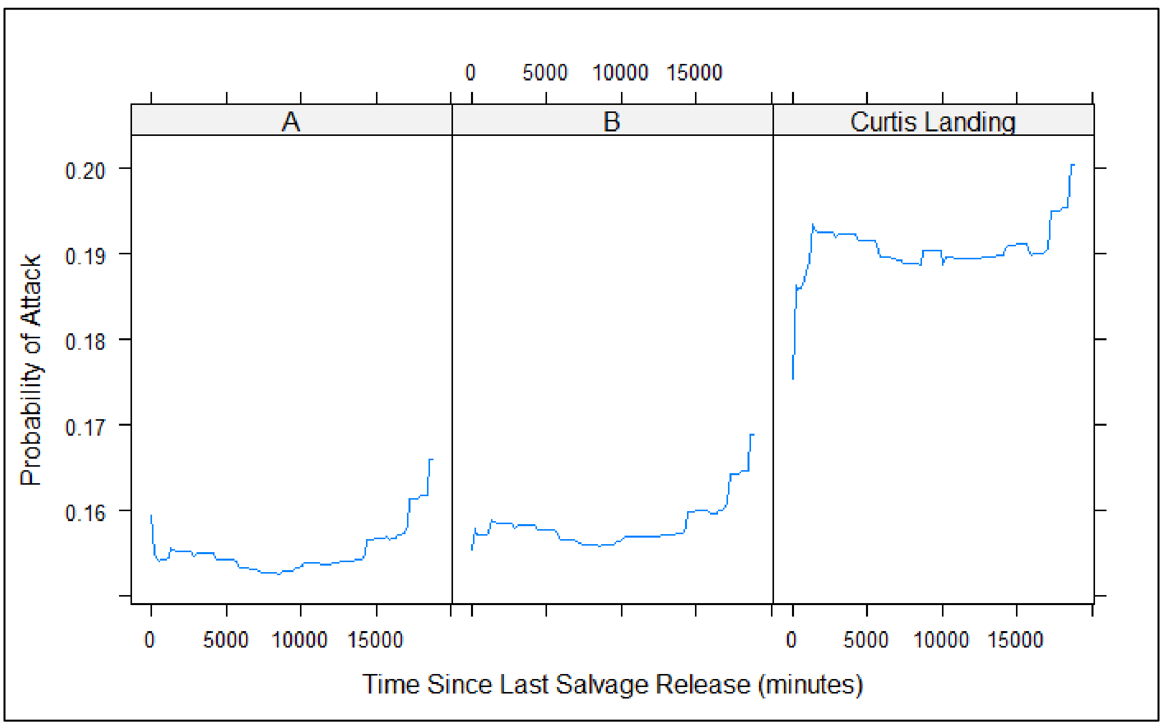

Figure A-6.—Partial dependence of attack probability on time since last salvage release across sampling locations.

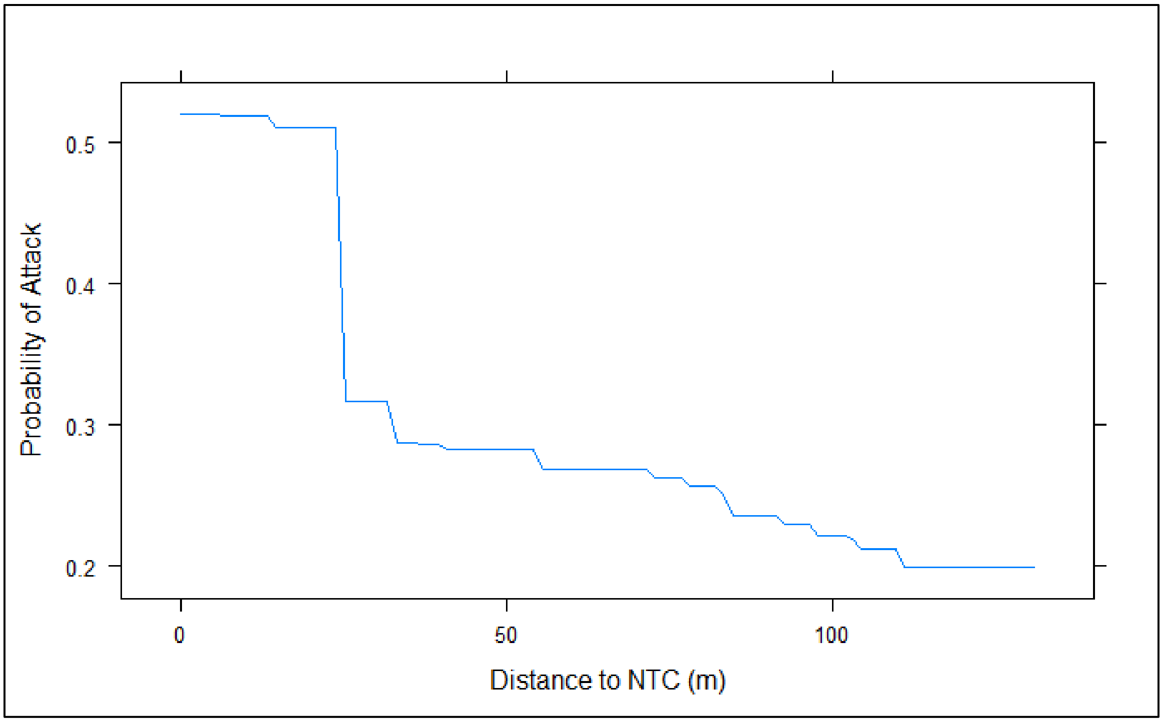

Figure A-7.—Partial dependence of attack probability on distance to center at Curtis Landing during daytime.

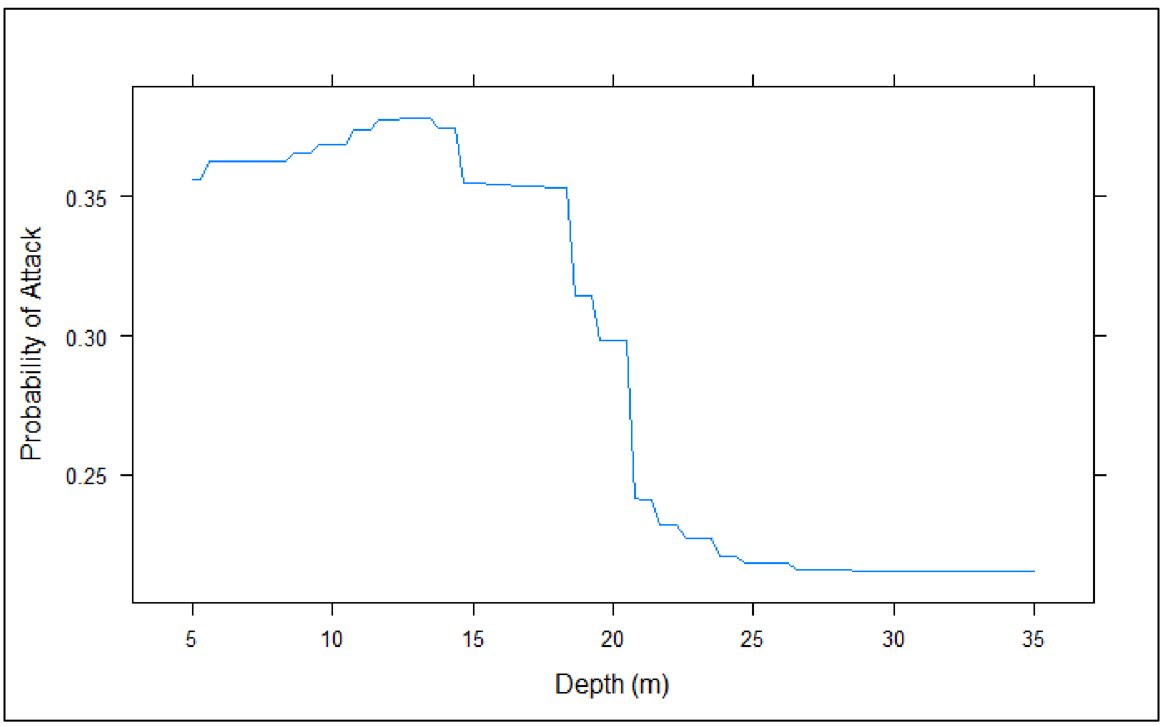

Figure A-8.—Partial dependence of attack probability on water depth at Curtis Landing during daytime.

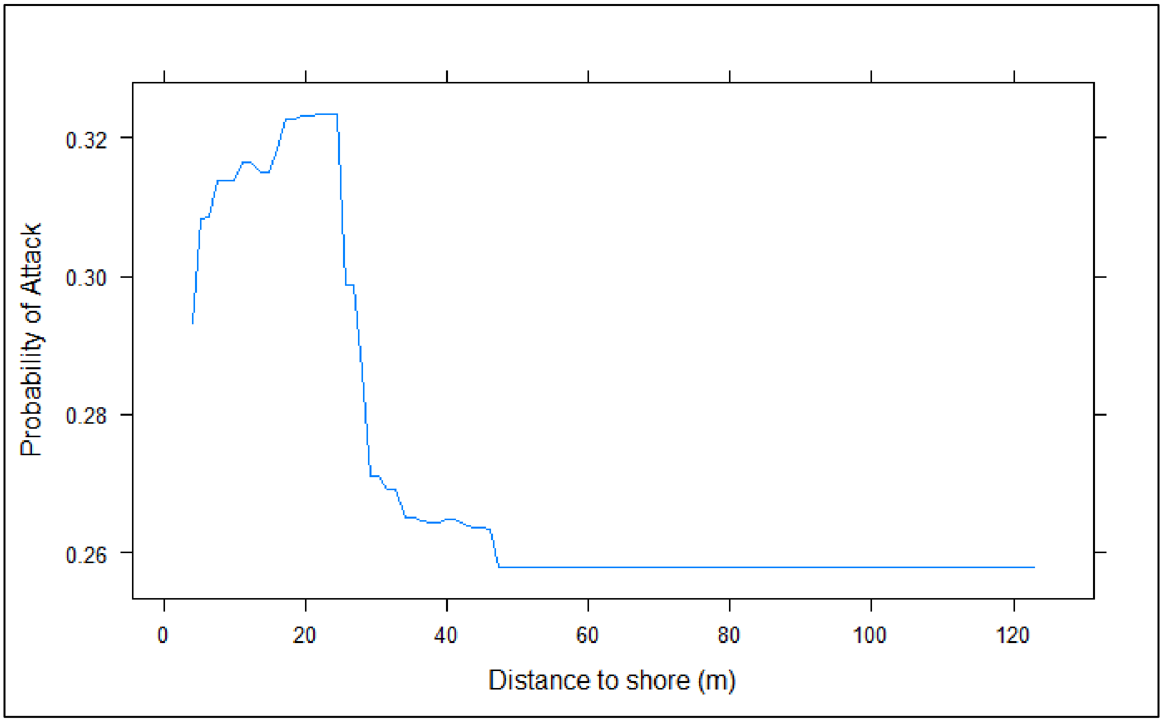

Figure A-9.—Partial dependence of attack probability on distance to shore at Curtis Landing during daytime.

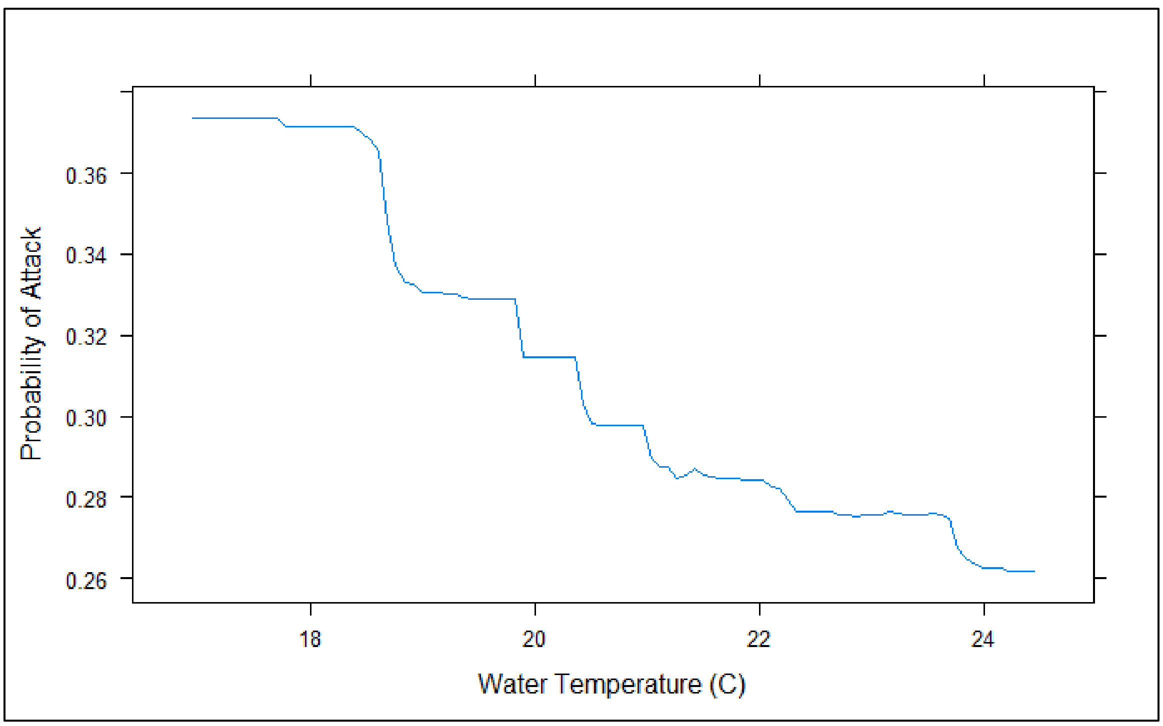

Figure A-10.—Partial dependence of attack probability on water temperature at Curtis Landing during daytime.

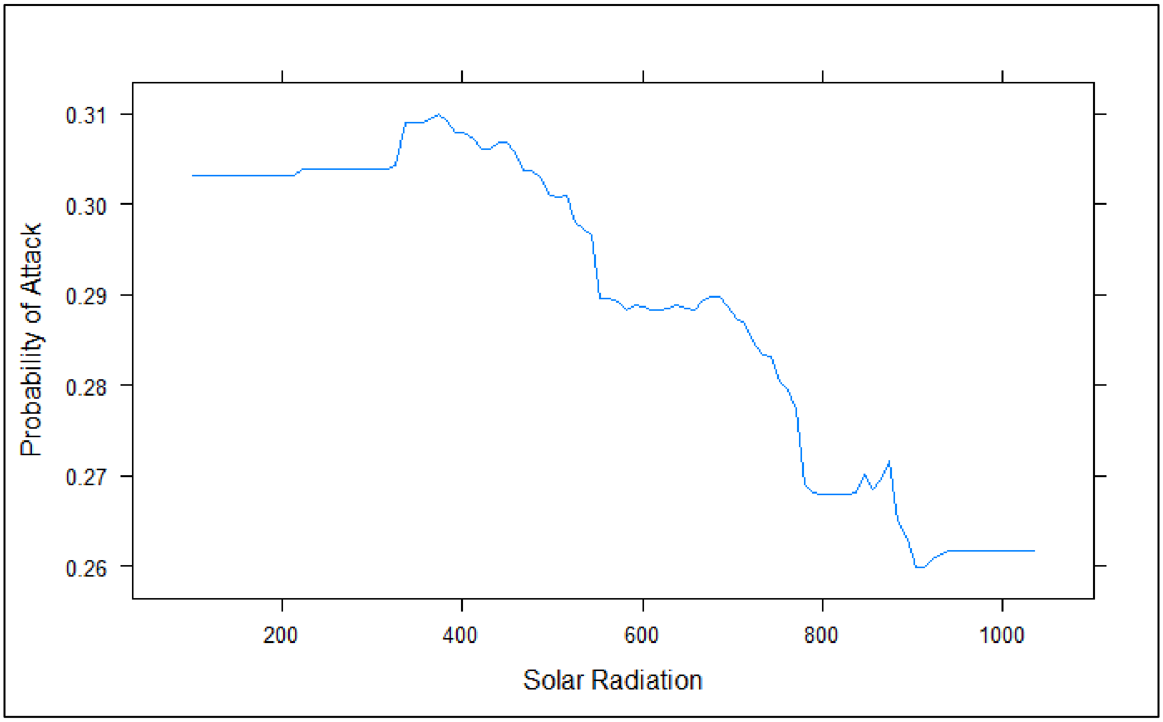

Figure A-11.—Partial dependence of attack probability on solar radiation at Curtis Landing during daytime.

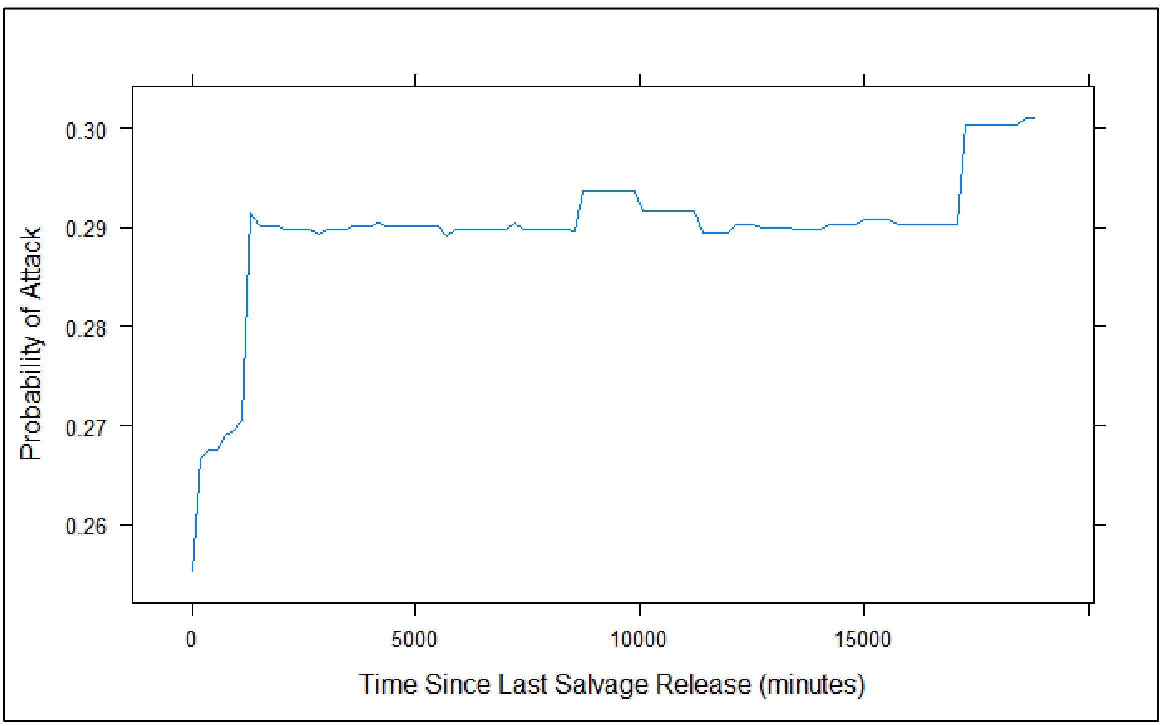

Figure A-12.—Partial dependence of attack probability on time since last salvage release at Curtis Landing during daytime.

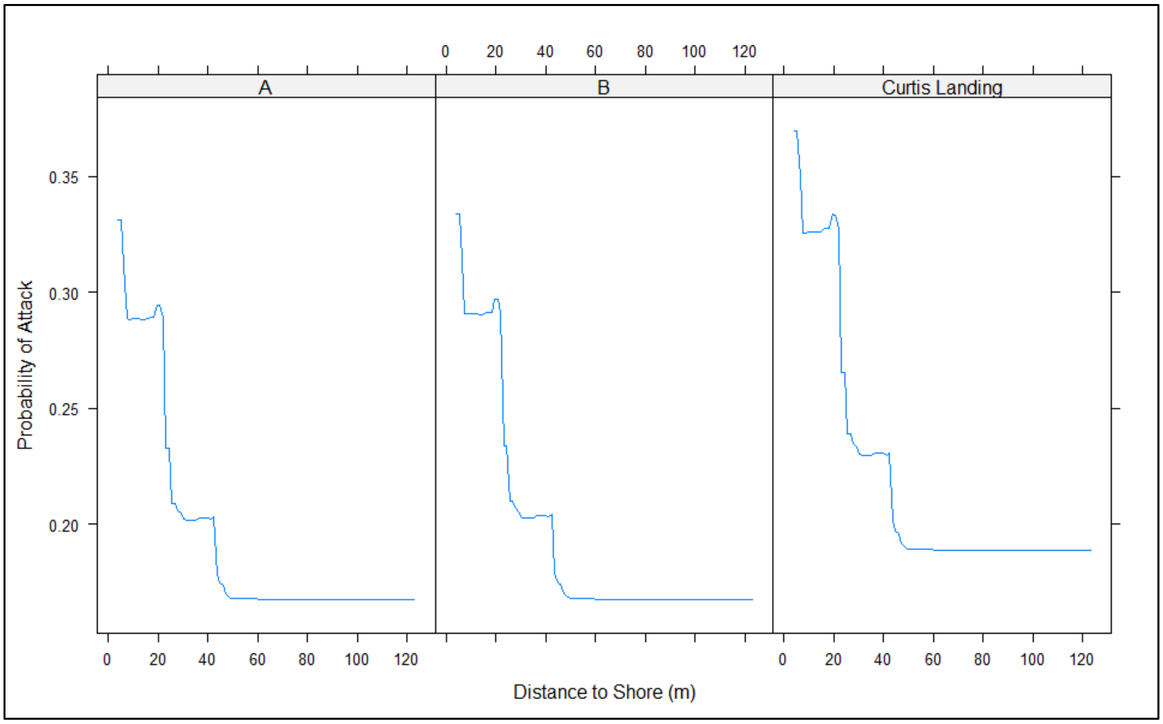

Figure A-13.—Partial dependence of attack probability on distance to shore (Cox BRT Model).

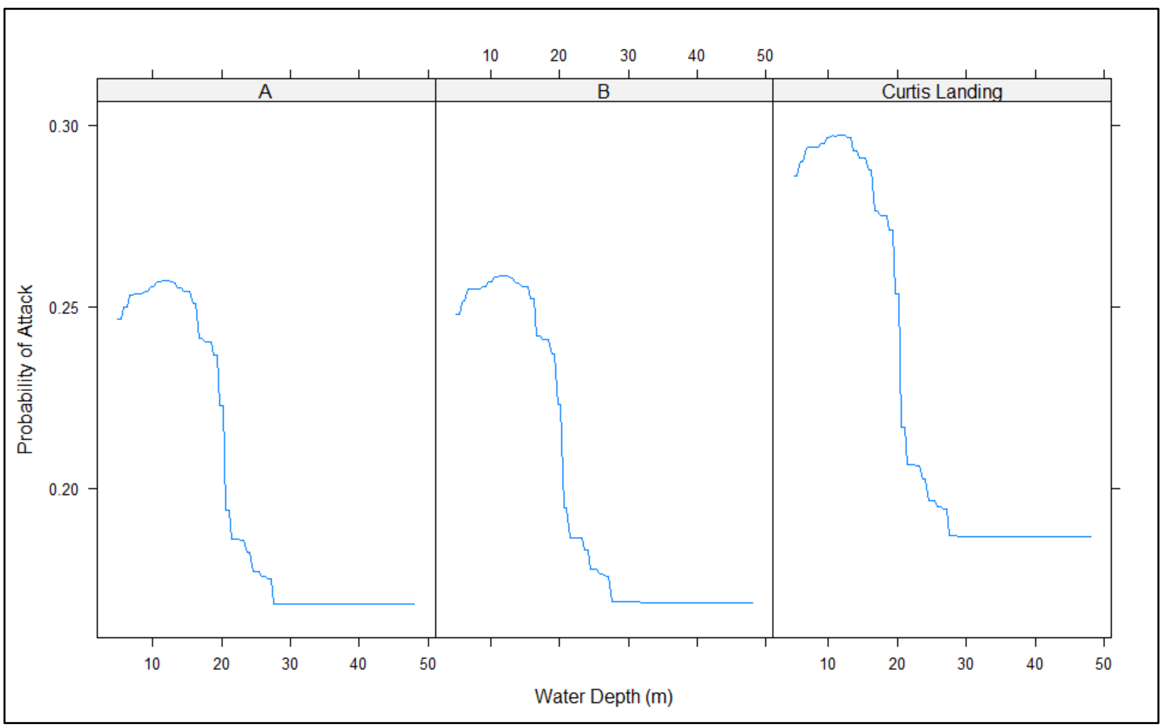

Figure A-14.—Partial dependence of attack probability on water depth (Cox BRT Model).

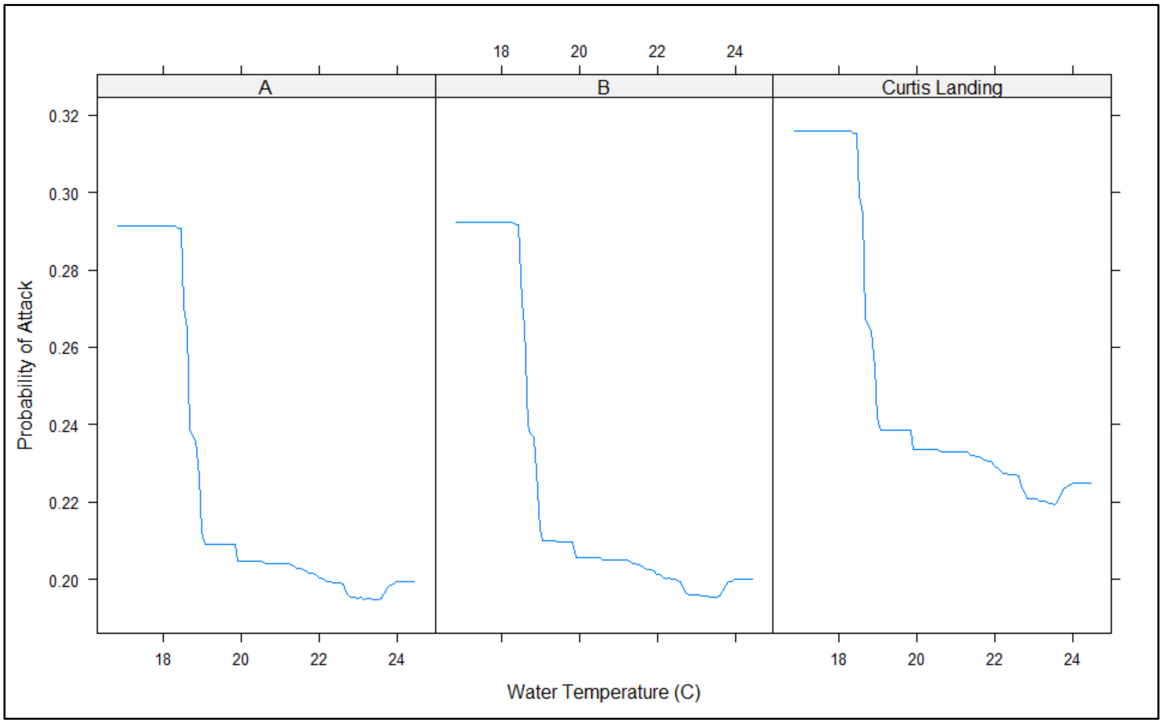

Figure A-15.—Partial dependence of attack probability on water temperature (Cox BRT Model).

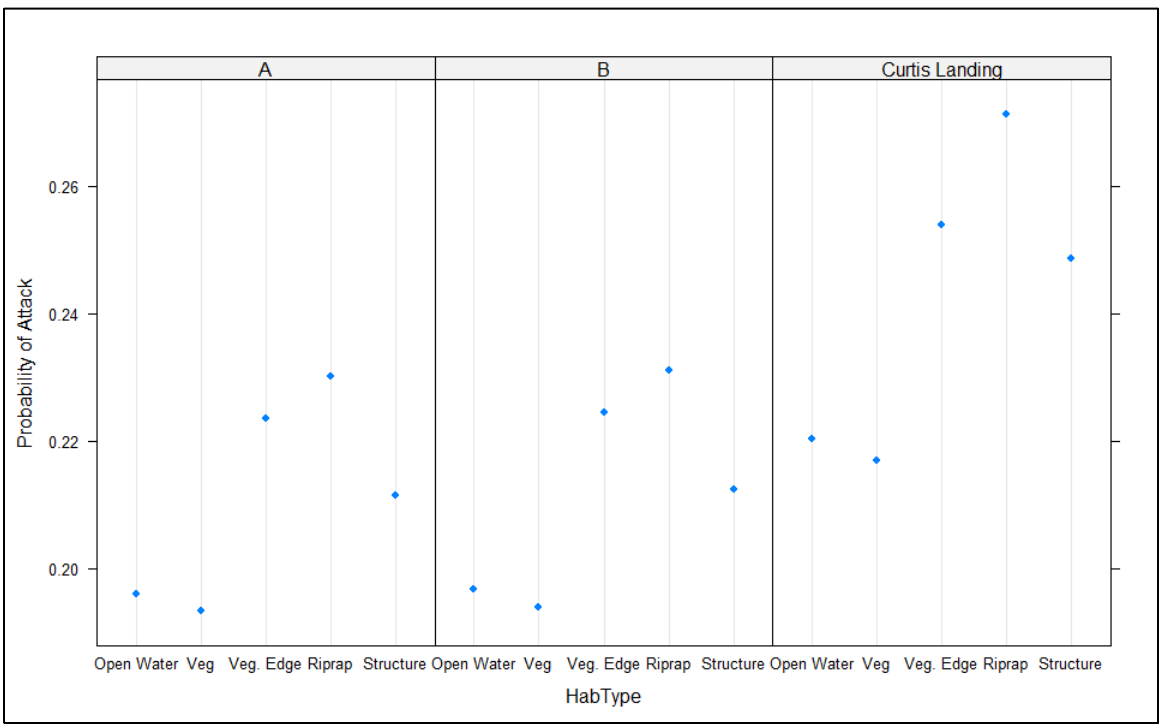

Figure A-16.—Partial dependence of attack probability on habitat type (Cox BRT Model).

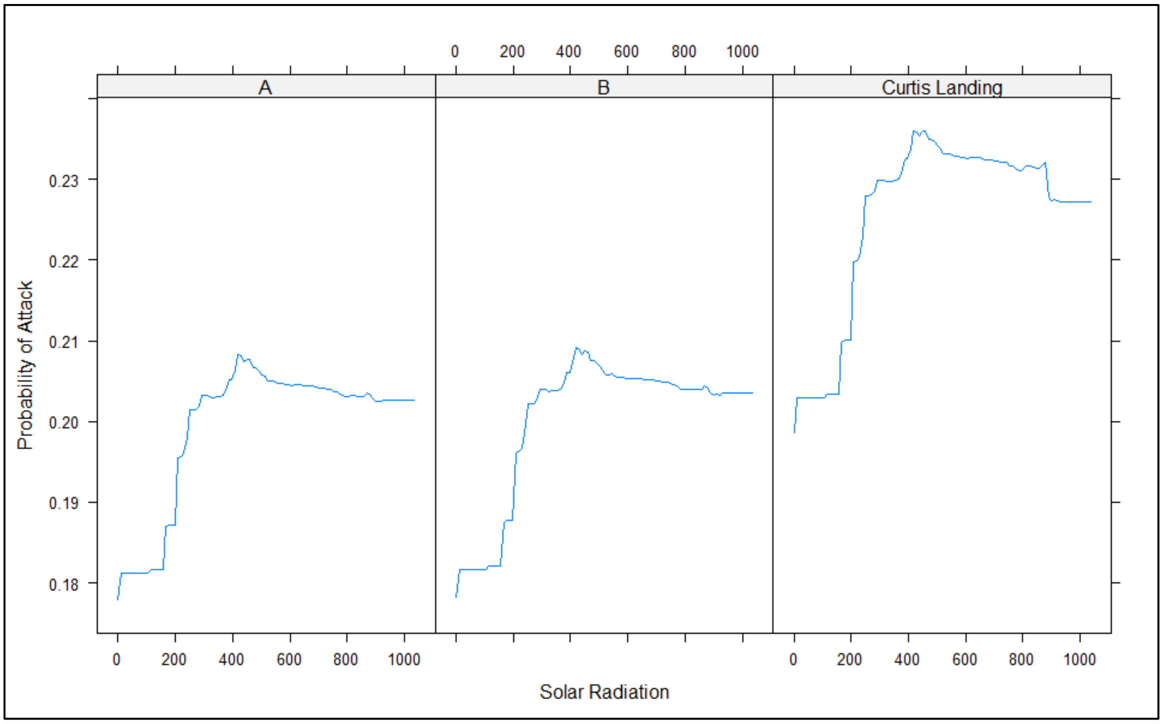

Figure A-17.—Partial dependence of attack probability on solar radiation (Cox BRT Model).

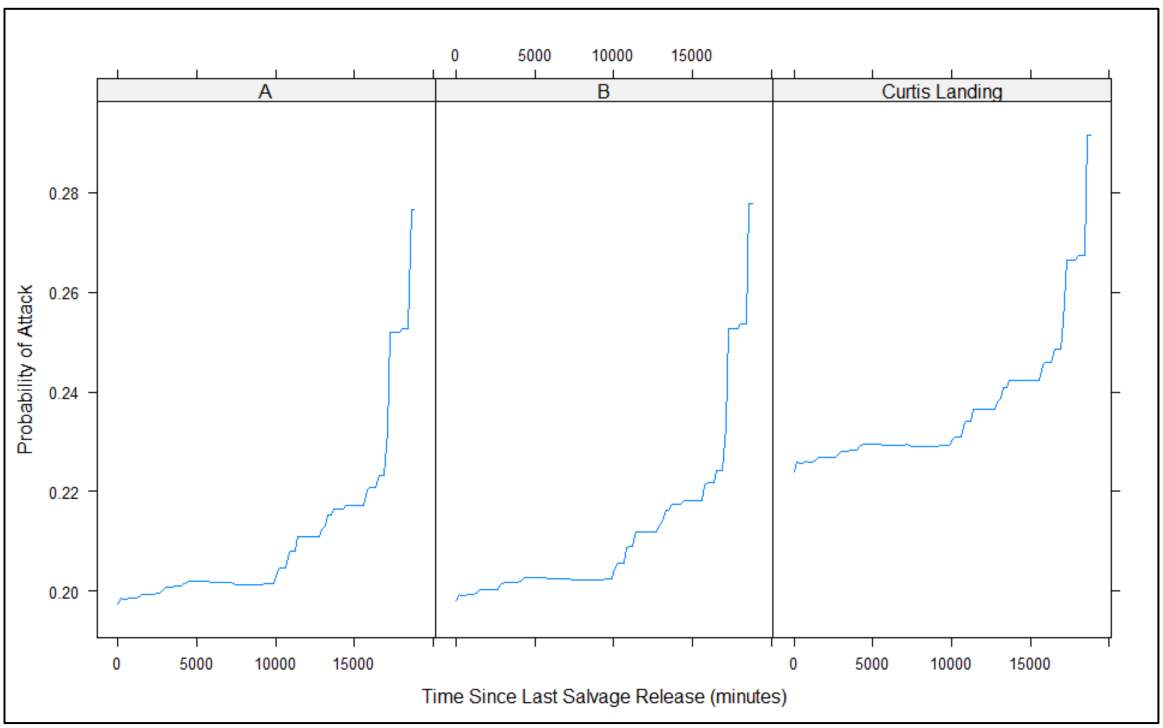

Figure A-18.—Partial dependence of attack probability on time since last salvage release (Cox BRT Model).