Caspian Tern Predation on Upper Columbia River Steelhead in the Priest Rapids Project: A Retrospective Analysis of Data from 2008 - 2010

Final Report

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SUMMARY

We evaluated avian predation of juvenile steelhead *Oncorhynchus mykiss* tagged (acoustic transmitter and passive integrated transponder) as part of behavioral and survival studies in the Priest Rapids Project (Wanapum and Priest Rapids dams and reservoirs) owned and operated by Public Utility District No. 2 of Grant County. Steelhead were tagged and released into the tailraces of Rock Island (n = 2,094), Wanapum (n = 1,925) and Priest Rapids (n = 1,905) dams, with avian predation rates calculated based on the percentage of tags deposited by birds on their nesting colonies during 2008-2010. The analysis focused on predation by a colony of Caspian terns *Hydroprogne caspia* nesting on Goose Island in Potholes Reservoir, WA.

Results demonstrated that Caspian tern predation was a substantial source of mortality, with terns nesting on Goose Island in Potholes Reservoir annually consuming 12.8% (95% confidence interval [c.i.] = 8.8 - 17.1), 20.8% (95% c.i. = 15.0 - 27.8) and 15.1% (95% c.i. = 10.4 - 20.7) of steelhead released into the tailrace of Rock Island Dam during 2008, 2009, and 2010, respectively. The majority of this predation (range = 56-73%) occurred within the Priest Rapids Project, with Project predation rates of 8.5% (95% c.i. = 5.3 - 12.0), 15.1% (95% c.i. = 10.0 - 21.1), and 8.4% (95% c.i. = 5.1 - 12.7) during 2008, 2009, and 2010, respectively. Reservoir-specific predation rates ranged from a low 4.0% (95% c.i. = 1.6 - 6.9) in the Priest Rapids Reservoir in 2010 to a high of 10.0% (95% c.i. = 6.2 - 14.6) in the Wanapum Reservoir in 2009. A positive association between the size of the Goose Island Caspian tern colony and steelhead predation rates was observed, with predation rates increasing with an increase in tern abundance (number of adults) on Goose Island.

Comparisons between survival rates and predation rates indicate that a substantial proportion of steelhead mortality within the Priest Rapids Project can be attributed to predation by Caspian terns nesting on Goose Island in Potholes Reservoir. Overall, an estimated 49%, 85%, and 37% of all steelhead mortality in the Priest Rapids Project during 2008, 2009, and 2010, respectively, could be attributed to predation by Caspian terns nesting on Goose Island. Small sample sizes of tagged fish, high incidence of tag failure, and differences in the detection efficiency of acoustic tags compared to PIT tags could have influenced the precision and accuracy of tern predation rate estimates. Regardless, results suggest that the average three-year Project survival requirement for smolts of 86.5% may have been achieved in the absence of predation on juvenile steelhead by Caspian terns nesting on Goose Island in Potholes Reservoir during 2008 - 2010.

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INTRODUCTION

Avian predation is a potential limiting factor in the recovery of Endangered Species Act (ESA) listed salmonid populations from the Columbia River (Collis et al. 2002; Evans et al. 2012). Caspian terns *Hydroprogne caspia*, double-crested cormorants *Phalacrocorax auritus*, American white pelicans *Pelecanus erythrorhyncho*, and several species of gull *Larus spp.* have all been identified as predators of anadromous juvenile salmonids. Of these, Caspian terns have been reported as having the highest per capita (per bird) predation rates on juvenile salmonids, especially impacts on steelhead *Oncorhynchus mykiss*, a species shown to be particularly vulnerable to Caspian tern predation in the Columbia River (Collis et al. 2001; Ryan et al. 2003; Antolos et al. 2005; Evans et al. 2012).

Caspian terns are colonial waterbirds that nest along coastlines, in estuaries, and at inland sites along rivers and lakes (Cuthbert et al. 1999). The breeding season for Caspian terns in North America generally occurs during April through July (Cuthbert et al. 1999), a time period that overlaps with the outmigration of juvenile salmonids in the Columbia River basin (FPC 2012). Caspian terns are considered strictly piscivorous and forage by plunge diving into the water to capture fish located near the surface. Records of Caspian terns nesting in southeastern Washington in the Columbia Plateau region date back to 1929 (Kitchin 1930), where a small colony of terns was observed nesting in Moses Lake, WA. Recently, Adkins et al. (2011) reported five Caspian tern colonies on the Columbia Plateau ranging in size from an average of 6 pairs on Sprague Lake, WA to an average of 424 pairs on Crescent Island on the Columbia River during 2004-2009.

One of the largest Caspian tern colonies on the Columbia Plateau resides on Goose Island in Potholes Reservoir, WA with an average colony size of 399 breeding pairs during 2008 - 2010 (BRNW 2012). Caspian terns nesting on Goose Island commute over 30 kilometers from Potholes Reservoir to the Columbia River to consume anadromous juvenile salmonids (Maranto et al. 2010). Studies of the diet composition of terns nesting at Goose Island indicate that salmonids comprise the minority of prey items in the diet, with roughly 10% - 30% of the annual diet composition consisting of juvenile salmonids (Maranto et al. 2010; BRNW 2012). Despite the low overall percentage of salmonids in the diet of terns nesting at Goose Island, predation of Endangered Species Act (ESA) listed juvenile steelhead by Caspian terns nesting at Goose Island have been substantial (Evans et al. 2012). Evans et al. (2012) estimated minimum predation rates on ESA-listed Upper Columbia River steelhead in excess of 10% of the population available below Rock Island Dam during 2008 - 2010. Expanding upon those results, Lyons et al. (2011) estimated that Upper Columbia River steelhead would likely accrue the greatest incremental benefit from plans to manage avian predators on the Columbia Plataea; in particular, management of Caspian terns nesting at Goose Island.

Juvenile salmonid survival standards established under the 2004 Biological Opinion for the Priest Rapids Project (Wanapum and Priest Rapids dams and reservoirs; hereafter “Project”) require 93% fish survival through each development (one dam and reservoir) or 86.5% through the entire Project (NMFS 2004). To evaluate whether these standards were met, Public Utility District No. 2 of Grant County (GPUD) conducted survival studies from 2008 to 2010. Survival studies utilized double-tagged (acoustic and passive integrated transponder [PIT]) steelhead smolts to track fish behavior (travel times and routes) and survival through the Project (Timko et al. 2011). Results indicated that steelhead survival standards were not met in the Priest Rapids Development (dam and reservoir) in 2008 - 2010 and

Wanapum Development in 2010 (Thompson et al. 2012). Timko et al. (2011) reported that recoveries of tags from steelhead released by GPUD on the Caspian tern colony at Goose Island during this time period ranged from ca. 4% - 8% of the fish released into the tailrace of Rock Island Dam; suggesting predation by Caspian terns was a substantial source of mortality.

Estimates of steelhead mortality by Goose Island Caspian terns documented in GPUD survival studies represent minimum estimates of predation because the estimates do not account for the detection efficiency of tags on bird colonies or the proportion of ingested tags that are either destroyed during digestion or are deposited by birds off-colony (at loafing or other areas used by the birds during the nesting season; Evans et al. 2012). For example, Evans et al. (2012) estimated that between 47% and 64% of PIT tags deposited by terns on Goose Island in Potholes Reservoir were not detected by researchers on the island. Data and modeling techniques to account and adjust for these sources of tag loss have recently been developed and if utilized would result in more accurate estimates of avian predation on juvenile steelhead tagged by GPUD during 2008 - 2010.

The primary goal of this study was to calculate predation rates by Goose Island Caspian terns on juvenile steelhead tagged by GPUD as part of survival studies in the Project during 2008 - 2010. Predation rate estimates were evaluated at various spatial and temporal scales to identify the location of predation and to more accurately quantify the over-all impact of tern predation on the survival of steelhead during outmigration. Additionally, tag recovery data collected at other nearby piscivorous waterbird colonies was examined to determine if other bird colonies posed a significant risk to steelhead survival in the Project.

METHODS

Study area.– Steelhead smolt collection and release locations were described in Timko et al. (2011) and are only briefly summarized here. Steelhead release sites included the tailraces of Rock Island Dam (river kilometer [rkm] 730), Wanapum Dam (rkm 669), and Priest Rapids Dam (rkm 639; Figure 1). Tags were recovered on nesting colonies of piscivorous waterbirds from the mouth of the Columbia River to the upper Columbia River. The report herein, however, focused on predation rates associated with a Caspian tern colony located on Goose Island, Potholes Reservoir (Figure 1) because the vast majority of tagged steelhead depredated by birds within the Project were recovered on Goose Island (see Results). Aerial flights (n = 2 per year) were used to determine colony size and habitat use of Caspian terns nesting at Goose Island in 2008 and 2009 (Adkins et al. 2011). In 2010, more intensive monitoring was conducted from blinds placed at the periphery of the tern colony. Additional data metrics recorded in 2010 include information on nesting chronology and weekly colony attendance (BRNW 2012).

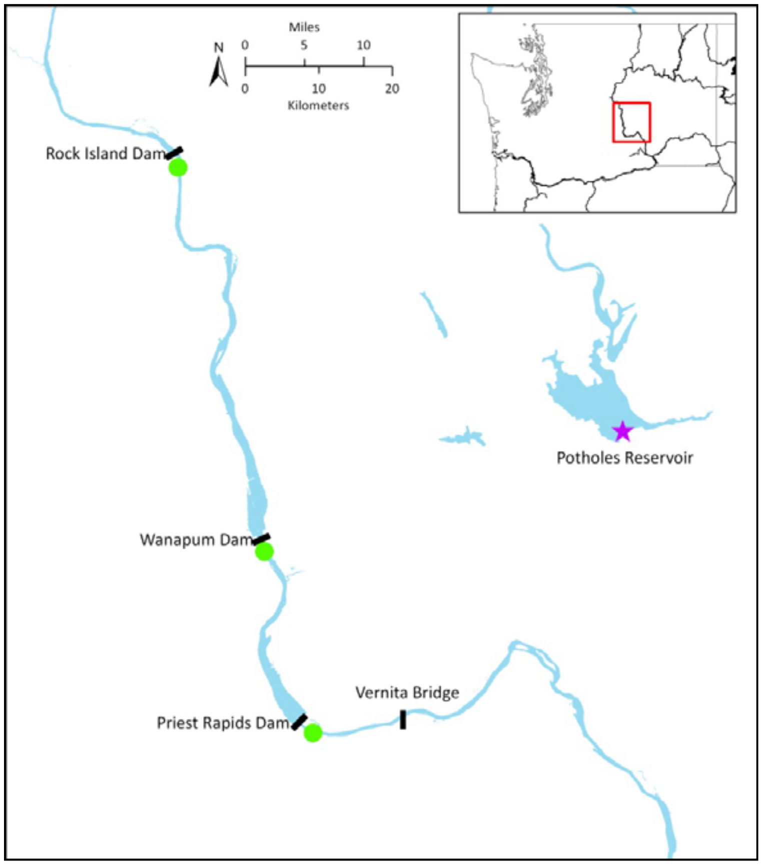

Figure 1. Study area from the Rock Island Dam tailrace (river kilometer [rkm] 730) to the Vernita Bridge acoustic detection array (rkm 624). Steelhead release sites (green circles) and the Goose Island, Potholes Reservoir Caspian tern colony (star) are noted.

Fish capture, tagging, and release.– Detailed methods on the collection, tagging, and release of steelhead used in this study were presented in Timko et al. 2011. Briefly, downstream migrating steelhead smolts were collected at Wanapum and Priest Rapids dams by dip-netting smolts from the wheel gate slots at each dam. Steelhead were anesthetized, implanted with a single combined acoustic transmitter and passive integrated transponder (PIT) tag (hereafter "tag"), held in recovery tank for approximately 24 hrs, and then released into the Columbia River. Steelhead were released by helicopter into the tailraces of Rock Island, Wanapum, and Priest Rapids dams (Figure 1). Tagged steelhead smolts were released during 8 May - 3 June in 2008 (Skalski et al. 2009), 2 - 25 May in 2009 (Skalski et al. 2010), and 4 - 31 May in 2010 (Skalski et al. 2011).

Recovery of tags on bird colonies.– Tagged steelhead smolts were considered to have been depredated by an avian predator if the unique tag code was detected on a bird colony. Tags were recovered from bird colonies after nesting birds dispersed following the breeding season each year (July - November). A detailed description of the methods used to recover PIT tags from bird colonies can be found in Evans et al. (2012). Specific to the Caspian tern colony at Goose Island, pole-mounted PIT tag antennas were used to detect PIT tags *in situ* by systematically scanning the area that was occupied by nesting Caspian terns. The nesting area was then swept with large magnets to remove tags from the surface. Removed tags were then individually scanned and the entire colony was then scanned again with pole-mounted PIT tag antennas. In general, the process was repeated until the number of previously undetected PIT tags found during a pass (i.e., a single scan of the entire colony) was ≤ 5% of the total number of PIT tags found during all previous passes.

Detection efficiency of PIT tags on bird colonies.– Not all PIT tags deposited by birds on the nesting colony are subsequently found by researchers after the nesting season. For example, tags can be blown off of the nesting area during wind storms, washed away during rain storms, or otherwise damaged or lost during the course of the nesting season. Furthermore, the detection methods used to detect PIT tags on bird colonies are not 100% efficient, as some proportion of detectable tags are missed by researchers during the scanning process (Ryan et al. 2003). To address these factors, PIT tags with known tag codes were intentionally sown on the Caspian tern colony at Goose Island (hereafter, "control PIT tags") throughout the nesting season to quantify PIT tag detection efficiency. Control PIT tags had the same dimension and length as PIT tags used to mark most juvenile salmonids from the Columbia River basin (12-mm, 134.2-kHz, full-duplex tags), but do not match the dimensions of tags used in this study (a combination acoustic tag and 8.5- mm full-duplex PIT tag; Timko et al. 2011). The sowing of control PIT tags was conducted during several discrete periods of the birds' nesting season: (1) prior to the initiation of egg laying (March - April), (2) during the egg incubation period (April - May), (3) during the chick rearing period (May - June), and (4) immediately after the fledging of young (July - August). These periods were selected because they encompassed the time periods when juvenile salmonids were out-migrating and therefore available as prey to nesting birds and occasions when the Caspian tern colony at Goose Island was accessible to researchers. During each period, 100 control PIT tags were randomly spread across the entire Caspian tern nesting area (Evans et al. 2012).

Off-colony deposition of PIT tags.– Not all PIT tags ingested by birds are subsequently deposited on their nesting colony. Tags can be damaged during digestion, stolen by other birds (kleptoparasitized), or regurgitated or defecated off-colony at loafing, staging, or other areas utilized by birds during the breeding season. The proportion of consumed steelhead tags that were deposited off-colony by Caspian terns nesting at Goose Island during this study was unknown. The only available empirical data to adjust Caspian tern predation rates for deposition were from previous studies investigating deposition rates of PIT tags by Caspian terns nesting at Crescent and East Sand islands (Lyons et al. 2011; BRNW 2012). These studies concluded that about 71% of PIT tags consumed by terns were subsequently deposited on their breeding colonies (95% c.i. = 62 - 81; A. Evans, unpublished data).

Avian predation rate calculations.– Predation rate calculations are identical to those of Evans et al. (2012), but were improved to incorporate deposition rate corrections. Incorporating off-colony deposition transforms minimum predation rate estimates (*sensu* Evans et al. 2012) to best estimates of predation rates.

Predation rates on tagged steelhead were calculated using an iterative multistep approach. First, logistic regression was used to interpolate daily colony specific detection efficiencies, whereby a binary response of control PIT tag detections (detected or not detected) was modeled as a function of time since control PIT tags were placed on the bird colony (eq. 1).

$$(1)\quad \hat{p}_j = \frac{e^{(\beta_0 + \beta_1 t_j)}}{1 + e^{(\beta_0 + \beta_1 t_j)}}$$

where $\hat{p}_j$ is the probability of detecting a tag deposited on day *j*, β_0 is the regression intercept, β_1 is the regression slope, and t_j is the independent variable for deposition date *j*. Second, the number of steelhead tags detected on the colony that were last detected alive on day *j* (r_j) was divided by the probability of detecting a tag deposited on day *j* ($\hat{p}_j$; eq.1) to estimate the number of steelhead PIT tags deposited on the colony on day *j* ($\hat{d}_j$) (eq. 2).

$$(2)\quad \hat{d}_j = {r_j}/{\hat{p}_j}$$

Recoveries of steelhead on an avian colony (r_j) only included steelhead tags recovered during the same year as release, since on-colony detection probability ($\hat{p}_j$) was year specific (eq.1). Next, to determine the total number of tagged steelhead consumed on day *j* ($\hat{c}_j$), the estimated number of steelhead PIT tags deposited on the colony ($\hat{d}_j$) was adjusted for on colony deposition rates ($\hat{n}_j$), the proportion of PIT tags that were likely egested on-colony versus off-colony (eq. 3).

$$(3)\quad \hat{c}_j = {\hat{d}_j}/{\hat{n}_j}$$

As previously stated, on-colony deposition rates for Caspian terns nesting at Goose Island was estimated at 0.71 (95% c.i. = 0.62 - 0.81) across all years. The total number of PIT-tagged steelhead consumed each day ($\hat{c}_j$) was then summed across all days of interests and divided by the total number available during this same time period (i.e., weekly or annual release periods).

Confidence intervals for predation rates were estimated by a bootstrapping simulation technique (Efron & Tibshirani 1986; Manly 1998). The bootstrapping analysis consisted of 2,000 iterations of all calculations, with each iteration representing a unique bootstrap resample (random sample with replacement) of all datasets: detection efficiency, on-colony deposition, steelhead releases, and tag recoveries on the Goose Island tern colony. The 2.5^{th} and 97.5^{th} quartiles were used to represent the limits of a 95% confidence interval.

To control for unstable results that might arise from small sample sizes, annual predation rates were only calculated when ≥ 500 PIT-tagged smolts were available in a given year (Evans et al. 2012). Analyses were conducted using R statistical software, with statistical significance set at $\alpha = 0.05$.

Spatially explicit predation rates.– Multiple acoustic arrays and subsequent acoustic tag detections of steelhead provided data to evaluate predation rates at various spatial scales. Spatially explicit predation rate estimates assume that a smolt was depredated downstream of the last array where it was detected alive and upstream of the next array where it was not detected. Estimated detection probabilities at acoustic arrays were consistently at or near 100% (Skalski et al. 2009; Skalski et al. 2010; Skalski et al. 2011; Timko et al. 2010; Timko et al. 2011), supporting the assumption that smolts not detected at a downstream array were mortalities and not missed detections. Any departure from near 100% detection probability (e.g., failed acoustic tags) would lead to invalid estimates of spatially explicit predation rates.

Spatial scales used to estimate predation rates for this study included:

1. Total – Predation on all steelhead released in the Rock Island tailrace regardless of where it occurred (Figure 2).
2. Project-specific – Predation on steelhead from the Rock Island tailrace to the Priest Rapids Dam forebay acoustic array (Figure 2)[1]
3. Reach-specific – Predation on steelhead from the head of a reach (i.e., tailrace of the upstream dam) to the acoustic array at the end of the reach (i.e., downstream forebay array); reaches include: Wanapum Reservoir, Priest Rapids Reservoir, or Vernita Bridge (15 rkm section downstream of Priest Rapids Dam; Figure 2)

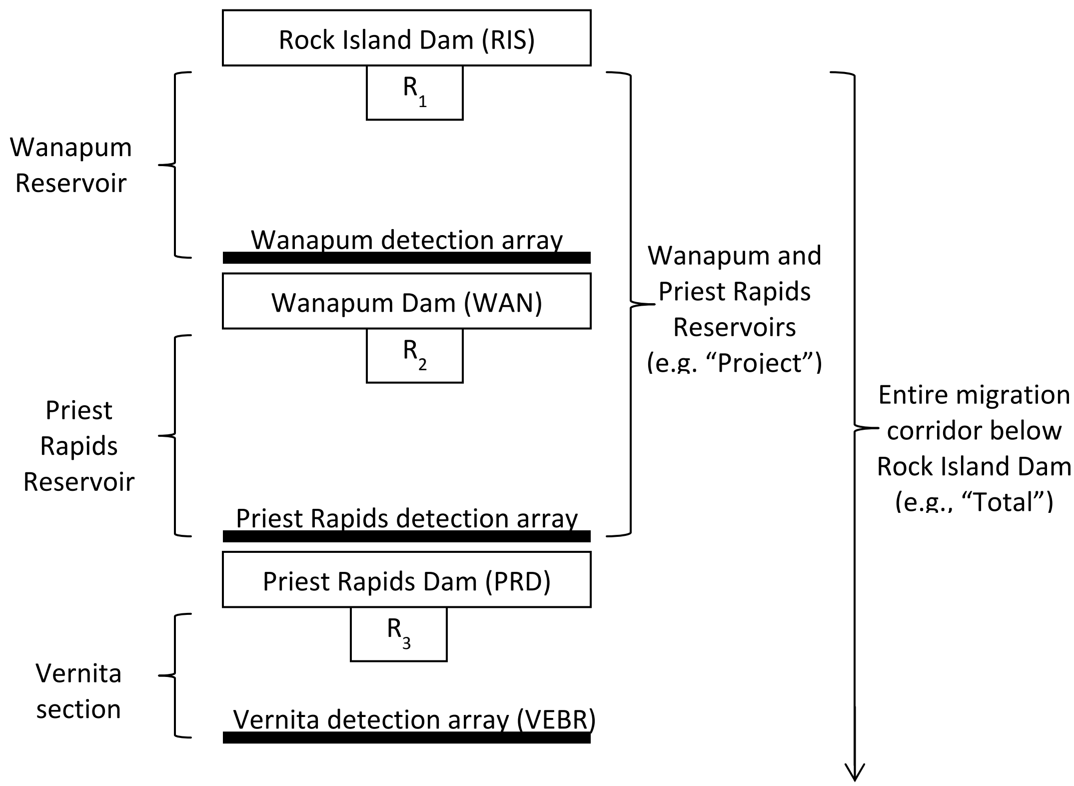

Figure 2. Definitions of spatial scales used to estimate predation rates by Goose Island, Potholes Reservoir Caspian terns on PIT and acoustic-tagged steelhead. R1, R2, and R3 represent three different release locations used in survival studies (see Timko et al. 2011 for release location and detection array details). Predation rates were defined as either (1) reach-specific (Wanapum Reservoir, Priest Rapids Reservoir, or Vernita section), (2) Project-specific (Wanapum and Priest Rapids reservoirs combined), or (3) total (predation on all steelhead released in the Rock Island tailrace).

[1] Predation rates on steelhead from the Rock Island tailrace to the Vernita Bridge acoustic array are also presented for reference.

Mortality attributable to tern predation.– *S*teelhead mortality between Rock Island and Priest Rapids dams may be attributable to multiple mortality factors (Thompson et al. 2012). Total mortality rates (1 – total survival rates) for this group of steelhead were obtained from previous reports (Skalski et al. 2009; Skalski et al. 2010; Skalski et al. 2011; Timko et al. 2011). Annual reach-specific predation rates and project-specific predation rates were divided by annual total mortality for those same sections to estimate the proportion of the total mortality rate attributable to predation by Caspian terns nesting at Goose Island. Although not precise (see *Assumptions*), these comparisons provided an evaluation of the proportion of total steelhead mortality within the Project attributable to predation by Caspian terns nesting at Goose Island in Potholes Reservoir.

Weekly predation rates.– Weekly predation rates were estimated using the predation rate methods noted above and grouping steelhead by release week. Sample size criteria were relaxed to ≥ 100 tagged smolts available per week, but increased confidence interval widths reflect this reduction in precision and lack of support for estimates with small sample sizes. Weekly total predation rates were compared to (1) weekly total predation rates from a different group of PIT-tagged steelhead released at Rock Island Dam (BRNW 2012), (2) weekly steelhead passage index at Rock Island Dam (sum of daily passage indices across a given week; FPC 2012), and (3) the maximum number of adult Caspian terns counted at Goose Island, Potholes Reservoir each week, which was only available in 2010 (BRNW 2012).

Per capita predation rates.– Predation rates adjusted for differences in the size of the Goose Island Caspian tern colony (number of breeding pairs) were generated for each year to address how potential changes in colony size might affect annual project-specific predation rates on tagged steelhead. Colony size-adjusted predation rates were calculated by dividing annual project-specific predation rates by the estimated number of breeding pairs at the colony in each year. Annual project-specific predation rates adjusted for colony size are presented for 100 breeding pairs. The numbers of breeding pairs at the Goose Island Caspian tern colony were obtained from Adkins et al. (2011). Measurements of uncertainty in breeding pair estimates in 2008 and 2009 were not available due to lack of in-season colony monitoring (BRNW 2012), therefore results are presented as best estimates and do not include 95% confidence intervals.

Assumptions.– Methods to calculate avian predation rates on tagged steelhead as part of this study were based on the following assumptions:

- A1. Salmonid release, recovery, and detection information were complete and accurate.
- A2. Tagged steelhead released or interrogated at a site were available to avian predators downstream of that site.
- A3. Tags from consumed steelhead were deposited on the Goose Island Caspian tern colony the same day they were last detected alive.
- A4. The detection probability for on-colony deposited control PIT tags was equal to that of naturally on-colony deposited acoustic/PIT tags by birds nesting at Goose Island.
- A5. Previously estimated off-colony PIT tag deposition rates represent off-colony deposition rates for birds and tags used in this study.

To satisfy assumptions A1 and A2, only steelhead that met criteria for survival studies (Skalski et al. 2009; Skalski et al. 2010; Skalski et al. 2011) were included in analysis of avian predation. Full descriptions of those criteria are available in Skalski et al. (2009, 2010, and 2011). Assumption A3 relates to the use of the last date of live acoustic detection as a proxy for the date a PIT tag was deposited on a bird colony. Assumption A3 only needs to be roughly true as on-colony detection efficiency did not change dramatically on a daily basis (see Results).

It is possible that on-colony detection efficiency of control PIT tags (A4) was slightly lower than that of acoustic/PIT tags used in this study (see Results). Movement of PIT tags off the colony due to wind and rain may disproportionately affect control PIT tags relative to the heavier acoustic/PIT tags used in this study. Caspian tern on-colony deposition rates of PIT tags (A5) are influenced by numerous factors including the rates of damage during ingestion or egestion, kleptoparasitism by gulls, or off-colony regurgitation of tags. On-colony deposition rate studies to date have only investigated deposition rates of PIT-tagged fish by Caspian terns nesting on islands in the Columbia River (Lyons et al. 2011). Violations of assumption A5 could have occurred due to (1) differences in deposition rates of acoustic/PIT tagged fish versus PIT tagged fish and (2) applicability of deposition rates measured at colonies located on the Columbia River (e.g., Crescent Island in McNary Reservoir) to a colony located more than 30 km from the Columbia River. At this time there is no empirical data to support or refute substantial violations of assumption A4 or A5, thus existing data on Caspian tern on-colony PIT tag detection efficiencies (Evans et al. 2012) and deposition rates (Lyons et al. 2011) were used in this study.

RESULTS

Fish capture, tagging, and release.– Complete descriptions of steelhead capture, tagging, and release results are summarized in Skalski et al. (2011) and Timko et al. (2011). Analysis of avian predation rates incorporated a total of 5,924 tagged steelhead released at three locations; the tailrace of Rock Island Dam (n = 2,094), the tailrace of Wanapum Dam (n=1,925), and the tailrace of Priest Rapids Dam (n = 1,905) during 2008 - 2010 (Table 1). The number of tagged steelhead released by location and year ranged from 605 (Priest Rapids Dam tailrace in 2008) to 797 (Rock Island Dam tailrace in 2009; Table 1).

Recovery of tags on bird colonies.– Caspian terns nesting at Goose Island depredated steelhead in each reservoir within the Project and in the reach below the Project (Table 1). Recoveries varied by year, but were always ≥ 1 in each reach, in each year (Table 1).

Table 1. Recoveries of GPUD steelhead tags on the Caspian tern colony at Goose Island, Potholes Reservoir. Reach-specific tag recoveries were determined by the last location a steelhead was detected alive from release into the tailrace of Rock Island (RIS), Wanapum (WAN), or Priest Rapids (PRD) dams and downstream detections at acoustic arrays (see Methods). Releases (N) only included those smolts used for acoustic survival studies (Skalski et al. 2009, 2010, and 2011). Recoveries only include those smolts that were recovered in the same year they migrated (see Methods).

		Recoveries by Reach/River Segment				
Release Location	N	RIS-WAN	WAN - PRD	PRD-VEBR	Below VEBR	Total
Rock Island Tailrace						
2008[a]	648	16	8	1	11	36
2009	797	22	12	1	12	47
2010	649	15	6	3	14	38
Wanapum Tailrace						
2008[a]	626	NA	11	2	6	19
2009	649	NA	15	2	24	41
2010	650	NA	9	2	12	23
Priest Rapids Tailrace						
2008[a]	605	NA	NA	1	19	20
2009	650	NA	NA	2	26	28
2010	650	NA	NA	4	33	37

[a] High acoustic tag failure rates in 2008 (Skalski et al. 2009) likely bias reach-specific designations to an unknown degree.

In total, 812 of the 5,924 steelhead tags (14%) were recovered on 16 different bird colonies in the Columbia River basin (Appendix A.1). Tags from steelhead removed from within the Project (i.e., released below Rock Island Dam and last detected at or upstream of the Priest Rapids Dam) were recovered on 8 different bird colonies, with the majority of recovered tags (114 out of 129 recovered tags or 88%) found on the Caspian tern colony at Goose Island (Appendix A.2). Some of the tags removed by birds from within the Project were detected on colonies that were > 200 Rkm downstream of Priest Rapid Dam, including the Caspian tern and double-crested cormorant colonies on East Sand Island in the Columbia River estuary (631 Rkms from Priest Rapids Dam). Because it is improbable that birds nesting at these far away colonies foraged within the Project, these tags likely failed (stopped transmitting) and were erroneously assigned as predation events within the Project. The disproportionate number of tags found in 2008 (e.g., 9 tags from colonies > 200 Rkm downstream of Priest Rapids Dam) relative to 2009 and 2010 (zero tags from colonies > 200 Rkm) independently support conclusions regarding high acoustic tag failure rates in 2008 (Skalski et al. 2009). For the purposes of this study, data from 2008 were included in the analyses presented here. Reach-specific and project-specific results from 2008, however, should be viewed with caution due to violation of assumption A1 (accurate acoustic tag detection histories).

Steelhead smolts originating from hatcheries in the Columbia River basin were not always marked (i.e., adipose fin clipped or elastomer tagged; FPC 2012). During the handling and tagging process for this study, all steelhead smolts with clipped adipose fins were classified as hatchery origin, but smolts without fin clips were a mixture of hatchery and wild origin rear-types (L. Sullivan *pers comm*.). Recoveries of steelhead smolts by known hatchery origin (clipped) or unknown origin (unclipped) are presented in Appendix A.3. Predation rates by rear-type, however, were not calculated for these groups due to small sample sizes and the likely inclusion of hatchery steelhead smolts in the wild origin group.

PIT tag detection efficiency.– In all years, there was a positive association between on-colony detection efficiency of control PIT tags sown on the Goose Island tern colony and date, whereby the probability of recovering a deposited PIT tag was higher for tags deposited later in the nesting season as compared to tags sown early in the nesting season (Table 2). Estimated on-colony detection efficiency for PIT tags deposited on the Goose Island tern colony when tagged steelhead were available ranged from 0.36 (early-May 2009) to 0.64 (late-May 2008; Table 2). Many factors influence on-colony detection efficiency. For instance, control PIT tags sown on the tern colony early in the nesting season have a greater chance of being transported off colony by extreme weather events that occur throughout the breeding season (Evans et al. 2012).

Table 2. Estimated on-colony PIT tag detection efficiency (95% confidence interval) on the Goose Island, Potholes Reservoir Caspian tern colony in early, mid-, and late May. Data derived from Evans et al. (2012) using control PIT tags sown on the colony (see Methods).

		Detection Efficiency		
Year	Control Tags	1-May	15-May	31-May
2008	400	0.52 (0.46-0.58)	0.58 (0.52-0.63)	0.64 (0.59-0.69)
2009	400	0.36 (0.30-0.42)	0.40 (0.35-0.46)	0.46 (0.41-0.51)
2010	400	0.39 (0.32-0.46)	0.49 (0.43-0.55)	0.61 (0.56-0.67)

Spatially explicit predation rates.– Total predation rates (i.e., predation on all steelhead released at RIS) by terns nesting at Goose Island were 12.8% in 2008 (95% c.i. = 8.8 - 17.1), 20.8% in 2009 (95% c.i. = 15.0 - 27.8), and 15.1% in 2010 (95% c.i. = 10.4 - 20.7; Table 3). Project-specific predation rates (i.e., RIS tailrace to PRD forebay) by terns nesting at Goose Island were 8.5% in 2008 (95% c.i. = 5.3 - 12.0), 15.1% in 2009 (95% c.i. = 10.0 - 21.1), and 8.4% in 2010 (95% c.i. = 5.1 - 12.7; Table 3). In each year, the majority of all predation by terns nesting at Goose Island occurred while steelhead were within the Project (range = 56 - 73%; Table 3) for steelhead that had to navigate the entire Project (i.e., based on fish released into the RIS tailrace).

Table 3. Annual predation rates (95% confidence interval) on acoustic tagged steelhead released (N) at Rock Island Dam (RIS) by Caspian terns nesting at Goose Island, Potholes Reservoir. Predation rates are provided for RIS to Wanapum Dam (WAN), RIS to Priest Rapid Dam (PRD), RIS to Vernita Bridge (VERB), and RIS to the Pacific Ocean (OCEAN). Recoveries (R) only included smolts that were recovered in the same year they migrated (see Methods). Predation rates were adjusted for on-colony PIT tag detection efficiency (estimated deposited) and off-colony PIT tag deposition (estimated consumed).

Year Reach	N	R	Estimated Deposited[a]	Estimated Consumed	Predation Rate	Percent of Total Tern Predation
2008[b]						
RIS-WAN	648	16	26 (15-40)	37 (20-56)	5.7% (3.1-8.7)	45% (36-51)
RIS-PRD	648	24	39 (24-56)	55 (35-78)	8.5% (5.3-12.0)	66% (61-70)
RIS-VEBR	648	25	41 (26-58)	57 (36-81)	8.8% (5.5-12.5)	69% (63-73)
RIS-OCEAN	648	36	59 (41-79)	83 (57-111)	12.8% (8.8-17.1)	100%
2009						
RIS-WAN	797	22	56 (34-84)	79 (49-116)	10.0% (6.2-14.6)	48% (41-52)
RIS-PRD	797	34	86 (58-118)	121 (79-168)	15.1% (10.0-21.1)	73% (66-76)
RIS-VEBR	797	35	88 (61-121)	124 (83-171)	15.6% (10.4-21.4)	75% (69-77)
RIS-OCEAN	797	47	118 (86-158)	166 (120-222)	20.8% (15.0-27.8)	100%
2010						
RIS-WAN	649	15	27 (15-43)	39 (20-62)	5.9% (3.1-9.5)	39% (29-46)
RIS-PRD	649	21	39 (24-57)	55 (33-82)	8.4% (5.1-12.7)	56% (48-61)
RIS-VEBR	649	24	44 (27-63)	62 (39-90)	9.5% (6.0-13.9)	63% (57-67)
RIS-OCEAN	649	38	70 (47-93)	98 (68-134)	15.1% (10.4-20.7)	100%

[a] Analogous to the value used by Evans et al. 2012 to estimate minimum predation rates by Goose Island terns.
[b] High acoustic tag failure rates in 2008 (Skalski et al. 2009) may bias reach-specific designations to an unknown degree.

Reach-specific predation rates by terns nesting at Goose Island were highest in the Wanapum Reservoir, followed by the Priest Rapids Reservoir, and the river section between Priest Rapids Dam tailrace and the Vernita Bridge acoustic array (Table 4, Figure 3). Predation rates on steelhead in the Wanapum Reservoir ranged from 5.7% in 2008 (95% c.i. = 3.1 - 8.7) to 10.0% in 2009 (95% c.i. = 6.2 - 14.6; Table 4; Figure 3). Predation rates in the Priest Rapids Reservoir were also highest in 2009 (8.0%; 95% c.i. = 4.2 - 12.7; Table 4, Figure 3). Predation rates in the river section between Priest Rapids Dam tailrace and the Vernita Bridge were the lowest in all years, ranging from 0.4% in 2008 (95% c.i. = < 0.1 - 2.0) to 1.6% in 2010 (95% c.i. = 0.4 - 3.5; Table 4; Figure 3).

Table 4. Estimated annual reach-specific predation rates (95% confidence interval) on acoustic tagged steelhead by Caspian terns nesting at Goose Island, Potholes Reservoir. Predation rates are based on releases of steelhead (N) into the tailraces of Rock Island (RIS), Wanapum (WAN), and Priest Rapids (PRD) dams and downstream detections at acoustic arrays (see Methods). Recoveries (R) only included those smolts that were recovered in the same year they migrated (see Methods). Predation rates were adjusted for on-colony PIT tag detection efficiency (estimated deposited) and off-colony PIT tag deposition (estimated consumed).

Year Reach	N	R	Estimated Deposited[a]	Estimated Consumed	Predation Rate
2008[b]					
RIS-WAN	648	16	26 (15-40)	37 (20-56)	5.7% (3.1-8.7)
WAN-PRD	626	11	19 (8-31)	26 (12-43)	4.2% (1.9-6.8)
PRD-VEBR	605	1	2 (0-5)	2 (0-7)	0.4% (<0-1.2.0)
2009					
RIS-WAN	797	22	56 (34-84)	79 (49-116)	10.0% (6.2-14.6)
WAN-PRD	649	15	37 (19-58)	52 (27-82)	8.0% (4.2-12.7)
PRD-VEBR	650	2	5 (0-13)	7 (0-19)	1.1% (<0.1-2.9)
2010					
RIS-WAN	649	15	27 (15-43)	39 (20-62)	5.9% (3.1-9.5)
WAN-PRD	650	9	18 (8-33)	26 (10-45)	4.0% (1.6-6.9)
PRD-VEBR	650	4	7 (2-16)	11 (2-23)	1.6% (0.4-3.5)

[a] Analogous to the value used by Evans et al. 2012 to estimate minimum predation rates by Goose Island terns
[b] High acoustic tag failure rates in 2008 (Skalski et al. 2009) may bias reach-specific designations to an unknown degree.

Figure 3. Annual estimated reach-specific predation rates (95% confidence interval) on acoustic tagged steelhead by Caspian terns nesting at Goose Island, Potholes Reservoir during 2008 - 2010. Reach-specific predation rates only incorporated steelhead released at the upstream tailrace of that specific reach. Recoveries only included those smolts that were recovered in the same year they migrated (see Methods). Circles are proportional to predation rates, but do not indicate specific locations of predation within a reach.

Mortality attributable to tern predation.– The percentage of total steelhead project mortality (1-survival; Timko et al. 2011) attributable to predation by Caspian terns nesting at Goose Island ranged from 37% in 2010 to 85% in 2009 (Table 5). Reservoir-specific estimates showed even more variation, ranging from 41 - 100% in the Wanapum Reservoir and 31 - 67% in the Priest Rapids Reservoir (Table 5). Mortality attributable to tern predation in the Wanapum Reservoir was particularly high in 2008 and 2009 (Table 5). Results in 2008 suggested that avian predation accounted for > 100% of total mortality. This nonsensical result may be attributable to unusually high acoustic tag failure in 2008 (Skalski et al. 2009), which could result in misclassification of where predation occurred. Additionally, the possibility that predation rates were overestimated due to application of PIT tag specific detection efficiency and on-colony deposition rates to acoustic/PIT tags used in this study cannot be completely eliminated (see Methods: Assumptions), nor are inaccuracies associated with survival estimates in Wanapum Reservoir. Precision of predation rates are also low due to small sample sizes of released steelhead and highly variable on-colony detection efficiency at Goose Island.

Table 5. Total estimated steelhead mortality rates (1-survival[a]), reach-specific, and Project-specific predation rates (95% confidence interval) by Caspian terns nesting at Goose Island, Potholes Reservoir and the percent of total mortality due to Goose Island Caspian tern predation (range). Values greater than 100% may be due to numerous factors affecting both survival and predation rates (See Methods: Assumptions).

Year	Total Mortality[a]	Predation Rate	Mortality Due to Birds
(A) Rock Island Tailrace - Wanapum Dam[b]			
2008	0.04	0.06 (0.03-0.09)	> 100%
2009	0.06	0.10 (0.06-0.15)	> 100%
2010	0.14	0.06 (0.03-0.10)	41% (21-66)
(B) Wanapum Tailrace - Priest Rapids Dam[b]			
2008	0.14	0.04 (0.02-0.07)	31% (14-50)
2009	0.12	0.08 (0.04-0.13)	67% (35-106)
2010	0.10	0.04 (0.02-0.07)	41% (16-72)
(C) Rock Island Tailrace - Priest Rapids Dam[b]			
2008	0.17	0.08 (0.05-0.12)	49% (31-70)
2009	0.18	0.15 (0.10-0.21)	85% (56-118)
2010	0.23	0.08 (0.05-0.13)	37% (22-56)

[a] Total mortality values = 1 - survival rates presented in Timko et al 2011.
[b] Direct comparisons between total mortality estimates and predation rates assume zero bird predation between the dam forebay and tailrace (i.e., "concrete").

Weekly predation rates.– Weekly total predation rates were estimated for three weeks in each year when $\geq$ 100 tagged steelhead were released. Seasonally, steelhead tagged as part of this study were often released during the peak of steelhead out-migration, a time period when steelhead predation rates by Goose Island Caspian terns are generally the lowest (Figure 4; Evans et al. 2011). No consistent trend in predation rates was observed across these short time periods in each year (Figure 4). In general, predation rates on tagged steelhead for this project were higher than PIT-tagged steelhead released at Rock Island Dam by BRNW, but differences were not significant (Figure 4).

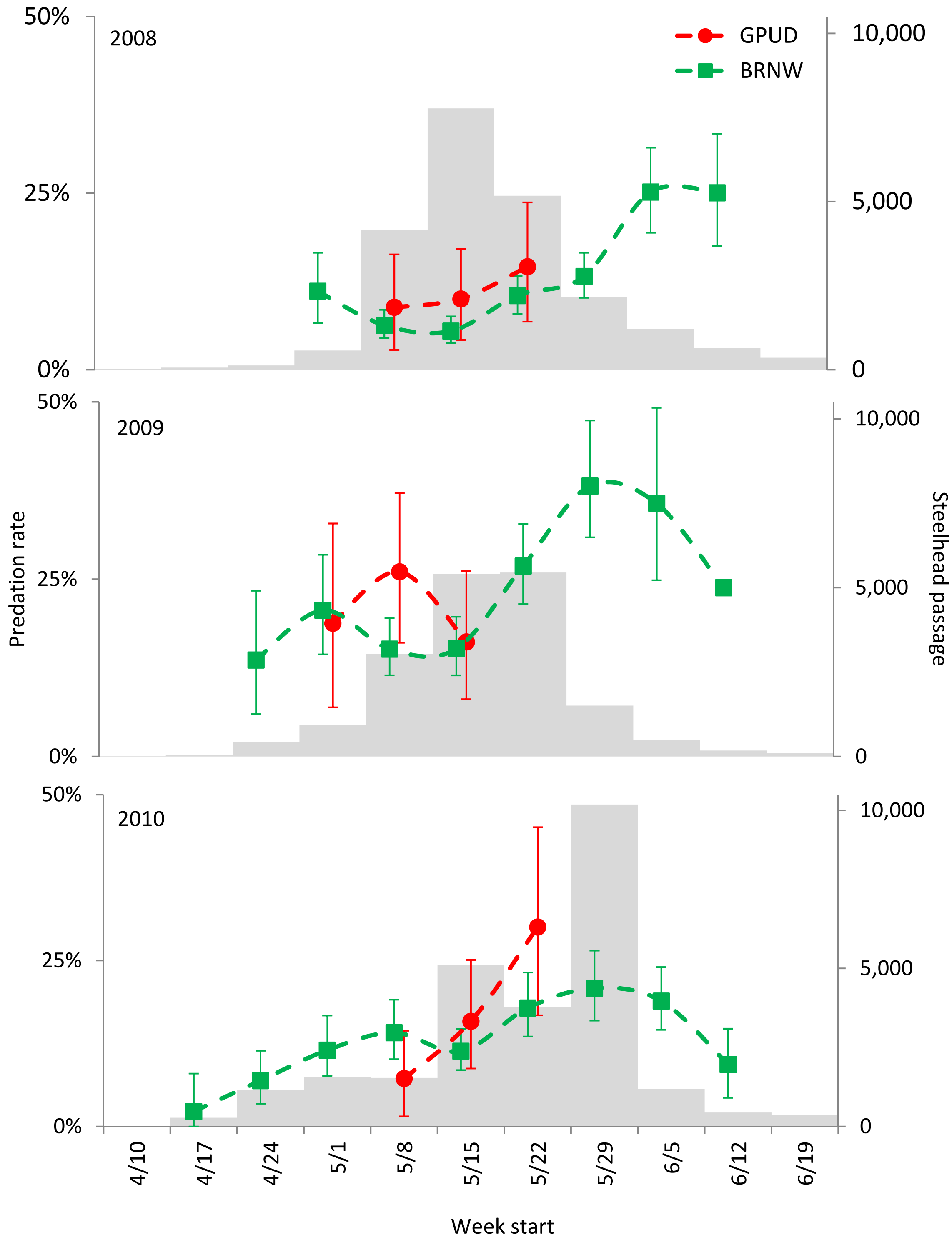

Figure 4. Weekly total predation rates on acoustic tagged steelhead released at Rock Island Dam as part of GPUD survival studies (GPUD; red circles) and Bird Research Northwest avian predation studies (BRNW; green squares) by Caspian terns nesting at Goose Island, Potholes Reservoir. Only weeks with > 100 steelhead released are presented. Error bars represent 95% confidence intervals. The steelhead passage index at Rock Island Dam each week is shown in grey (data from FPC 2012).

Per capita predation rates.– Total predation rates on steelhead by Caspian terns nesting at Goose Island increased as the number of Caspian tern breeding pairs increased (Figure 5). For instance, predation rates were highest in 2009 (20.8%), the same year that the Goose Island Caspian tern colony had the greatest number of breeding pairs (487 pairs; Figure 5; breeding pair estimates from Adkins et al. 2011).

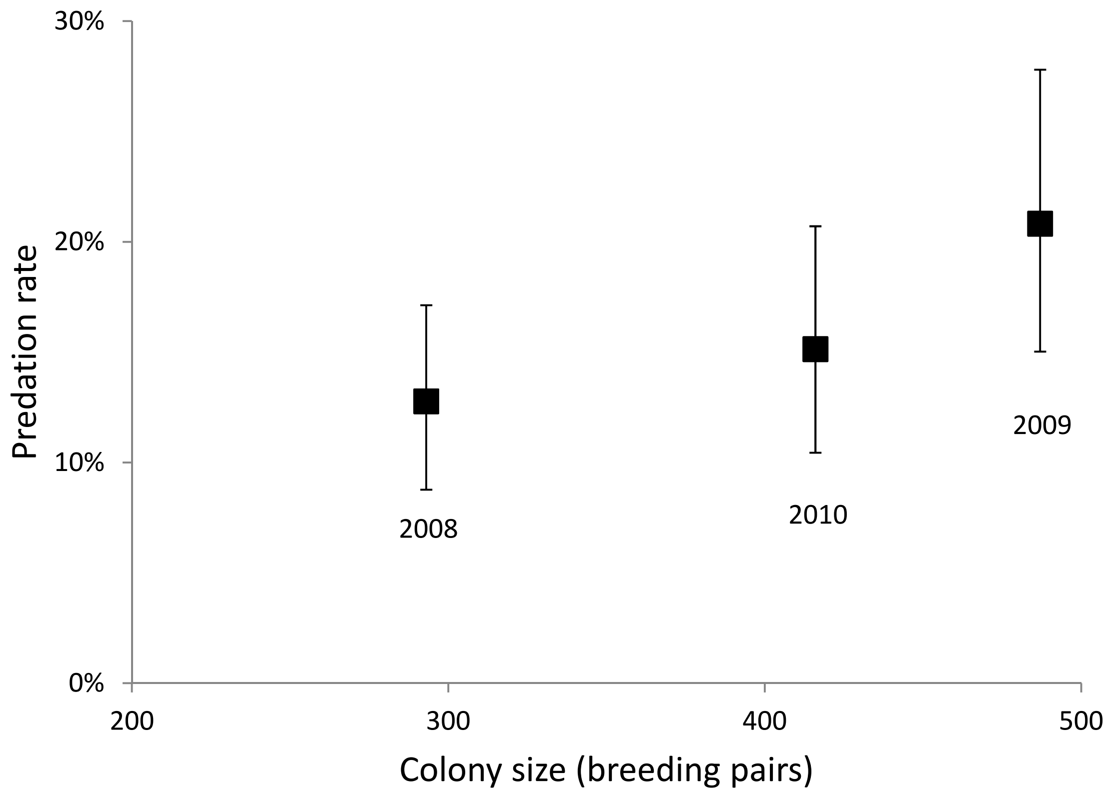

Figure 5. Annual total predation rates on acoustic tagged steelhead by terns nesting at Goose Island, Potholes Reservoir. Predation rates by Caspian tern colony size at Goose Island are plotted (Adkins et al. 2011; BRNW 2012). Error bars represent 95% confidence intervals; migration years are noted below each estimate.

Weekly total predation rates showed a similar within season trend, where predation rates often increased as weekly Caspian tern abundance at Goose Island increased (Figure 6). However, the small number of weeks with $\geq$ 100 tagged steelhead released (n = 3 weeks per year), the small number of tagged steelhead released per week (n = 136 - 341 smolts per week), and the lack of weekly bird abundance data in 2008 and 2009 prevent a thorough analyses of these associations.

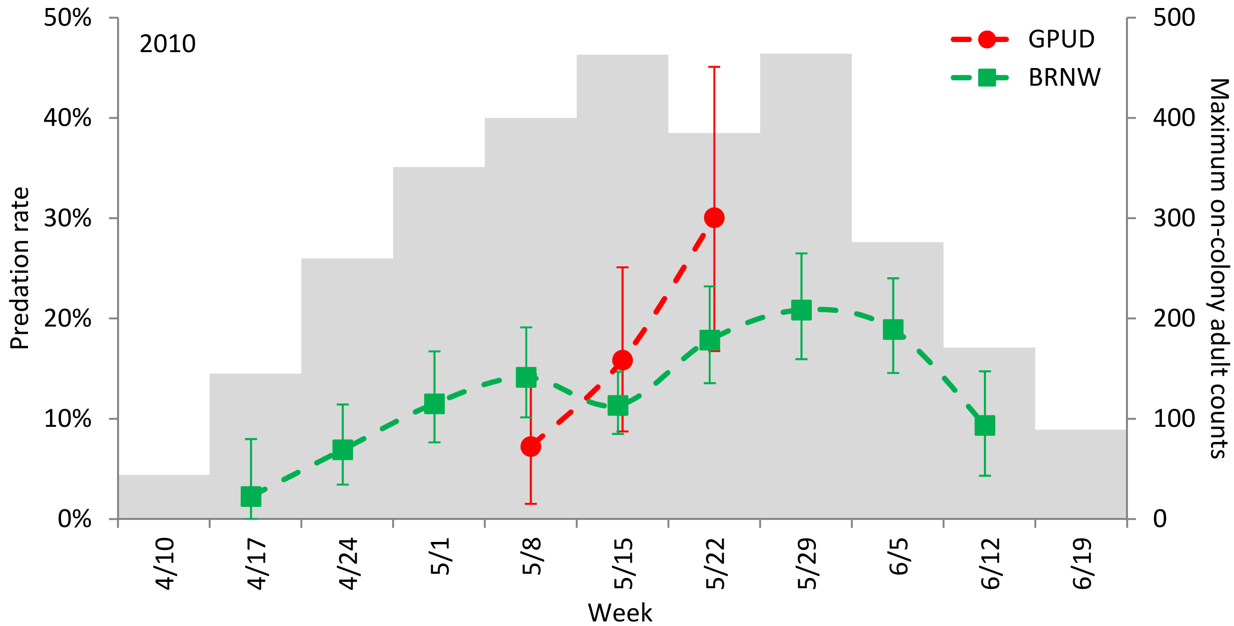

Figure 6. Weekly total predation rates on acoustic tagged steelhead released at Rock Island Dam as part of GPUD survival studies (GPUD; red circles) and Bird Research Northwest avian predation studies (BRNW; green squares) by Caspian terns nesting at Goose Island, Potholes Reservoir in 2010. Only weeks with ≥ 100 steelhead released are presented. Error bars represent 95% confidence intervals. The maximum number of adult Caspian terns counted at Goose Island each week is shown in grey (data from BRNW 2012). Weekly colony attendance data for Caspian terns at Goose Island were not available in 2008 or 2009.

Colony size-adjusted Project-specific predation rates (i.e., Project predation rates per 100 breeding pairs) were relatively stable across years. Colony size-adjusted Project predation rates ranged from 2.0 - 3.1% of tagged steelhead per 100 Caspian tern breeding pairs at Goose Island (Table 6).

Table 6. Annual colony size-adjusted Project-specific predation rates (per 100 breeding pairs) on acoustic tagged steelhead by Caspian terns nesting at Goose Island, Potholes Reservoir. Estimates only include steelhead released (N) in the Rock Island Dam tailrace (RIS) and consumed upstream of the Priest Rapids Dam forebay detection array (PRD).

Year	Reach	N	Predation Rate (95% c.i.)	Breeding Pairs	Predation Rate per 100 Pairs
2008	RIS-PRD	648	8.5% (5.3-12.0)	293	2.9%
2009	RIS-PRD	797	15.1% (10.0-21.1)	487	3.1%
2010	RIS-PRD	649	8.4% (5.1-12.7)	416	2.0%

DISCUSSION

Caspian tern predation was a substantial source of mortality for juvenile steelhead. Terns nesting on Goose Island in Potholes Reservoir annually consumed an estimated 12.8%, 20.8%, and 15.1% of steelhead released by GPUD into the tailrace of Rock Island Dam during 2008, 2009, and 2010, respectively. The majority (range = 56 - 73%) of this mortality occurred between Rock Island Dam and Priest Rapids Dam, indicating that for fish that must navigate the entire Project, Goose Island Caspian tern predation was greater within the Project than outside of the Project. Timko et al. (2011) reported that the majority of GPUD steelhead tags recovered on the Goose Island tern colony were of steelhead that already passed the Project (below Vernita Bridge). Timko et al. (2011) evaluations, however, included all release groups (i.e., Rock Island, Wanapum, and Priest Rapids dams) in one estimate, while estimates from this study were for steelhead that migrated the entire Project (i.e., released at Rock Island Dam).

Compared to other piscivorous waterbirds located in the mid-Columbia River, Caspian terns nesting on Goose Island had the greatest impact on steelhead survival reported in the literature. Weise et al. (2008) estimated that between 0.3% and 1.1% of available steelhead between Wells and Rock Island dams were annually consumed by a total of five different avian species (Caspian terns, double-crested cormorants, California and ring-bill gulls, and common mergansers *Mergus merganser*). Lyons et al. (2011) estimated an annual predation rate of 2.5% on Upper Columbia River steelhead by Caspian terns nesting on Crescent Island in the McNary Dam Reservoir. In fact, relative to non-avian documented mortality factors for steelhead, Goose Island Caspian tern predation was the highest single-source mortality factor reported. Dam passage mortality estimates for steelhead passing Priest Rapids and Wanapum dams ranged from < 1.0% to 4.8%, per dam, during 2008 - 2010 (Timko et al. 2011). Although estimates of the number or percentage of steelhead consumed by piscivorous fish in the mid-Columbia River are generally lacking, Thompson et al. (2012) noted that 2.6% of acoustic tagged juvenile steelhead migrating through the Priest Rapids Reservoir were potentially consumed by northern pikeminnows *Ptychocheilus oregonensis* and other piscivorous fish (e.g., smallmouth bass *Micropterus dolomieu)* in 2011.

Previous PIT tag predation rate studies, like those of Antolos et al. (2005), Maranto et al. (2010) and Evans et al. (2012) could not evaluate predation on different spatial scales. Use of acoustic telemetry data, however, provided information on where within the river steelhead were depredated by birds. Spatial analysis indicated reach-specific differences in predation rates existed, with rates consistently higher in Wanapum Reservoir, followed by the Priest Rapids Reservoir, and finally in the river segment between Priest Rapids Dam and Vernita Bridge. Differences in predation rates directly correspond to the total length of the river reach or segment (Rkm) and estimated travel times of steelhead through these various reaches/segments, with median travel times of tagged steelhead significantly greater in the Wanapum Reservoir (39.0 - 61.1 hrs, depending on the year) compared to the Priest Rapids Reservoir (13.2 - 24.6 hrs) and the segment of river between Priest Rapids Dam and Vernita Bridge (1.9 - 2.2 hrs) during 2008 - 2010 (Timko et al 2011). Differences in travel times, however, cannot explain differences in annual predation rates, whereby reach-specific, Project-specific, and cumulative predation rates in 2009 were nearly twice as high as predation rates in 2008 and 2010. Differences in the size (abundance) of the Goose Island Caspian tern colony were likely associated with predation rates, whereby increases in colony size were commensurate with increases in predation rates during the study. Hostetter et al. (2012) found a similar positive relation between colony size and Snake River steelhead predation rates at a colony of double-crested cormorants on Foundation Island in the McNary Dam Reservoir.

Future studies of the avian predation in the Priest Rapids Project would benefit from larger sample sizes of tagged fish, random selection and tagging of fish throughout the entire smolt outmigration period, and representative tagging in fish of different rearing types (i.e., hatchery and wild) and external conditions (i.e., good to poor). Although there was no significant difference in predation rates on GPUD and BRNW tagged steelhead released into the tailrace of Rock Island Dam, comparisons are compromised by small sample sizes of GPUD tagged fish and possible differences in recovery rates among double-tagged fish (i.e., GPUD) and single-tagged fish (BRNW). A higher detection efficiency or on-colony deposition rate of GPUD tagged (acoustic/PIT) fish on the Goose Island Caspian tern colony would bias (erroneously inflate) predation rate estimates compared to those of single-tagged (PIT) fish. Research aimed at evaluating detection efficiency and deposition rates in double-tagged fish would result in a more defensible and, potentially, accurate estimate of predation rates on acoustic tagged fish. An analysis of Caspian tern predation on steelhead by rear-type was also impacted by small samples sizes and the designation of unclipped hatchery fish as wild. BRNW (2012) and Lyons et al. (2011) reported that hatchery steelhead were more susceptible to Goose Island tern predation than wild fish, with predation rates in hatchery fish significantly higher than those of wild fish during 2007 - 2010. In a similar study, Hostetter et al. (2012) observed an association between the external condition of steelhead smolts and susceptibility to Caspian tern predation, whereby steelhead with noticeable external damage (body injuries, fungal infections, descaling) were more likely to be depredated by terns than steelhead without external damage.

Comparison between steelhead survival rates (presented in Timko et al. 2011) and tern predation rates indicate that a substantial proportion of all steelhead mortality within the Priest Rapids Project can be attributed to Caspian terns nesting on Goose Island in Potholes Reservoir. Over-all, an estimated 49%, 85%, and 37% of all steelhead mortality in the Project during 2008, 2009, and 2010, respectively, was attributed to predation by Caspian terns nesting on Goose Island. Reach-specific comparisons also indicated that a substantial proportion of all mortality in the Wanapum and Priest Rapids reservoirs was associated with Goose Island tern predation. Mortality in each reservoir and in the entire Project, however, is not limited to predation by Caspian terns nesting at Goose Island, with losses due to other piscivorous predators and dam passage also documented (Thompson et al. 2012).

Based on the results of this study, potential management to eliminate Caspian tern nesting at Potholes Reservoir will likely increase steelhead survival in the Priest Rapids Project. For example, results of this study suggest that the 93% survival standards for steelhead in the Priest Rapids Development (dam and reservoir) would have been achieved in both 2009 and 2010 if predation from Goose Island Caspian terns did not exist and other sources of mortality (e.g., pikeminnow predation, predation by other piscivorous birds, etc) did not compensate for reductions in Caspian tern predation. Reductions in Goose Island Caspian tern predation plus reductions in other sources of mortality (e.g., other piscivorous predators), however, would have likely been needed to meet steelhead survival standards in the Priest Rapids Development in 2008 and in the Wanapum Development in 2010. Over-all (all reaches, all years), results suggest that the average three-year Project requirement of 86.5%

survival may have been achieved in the absence of predation on juvenile steelhead by Caspian terns nesting on Goose Island. Per capita predation rate estimates suggest that even a colony as small as 100 breeding pairs would consume between 2.0 - 3.1% of available steelhead smolts between Rock Island and Priest Rapids dams. It is important to note, however, that tern management will only benefit smolt survival if reductions in avian predation translate into commensurate increases in smolt survival. If Caspian terns disproportionately consume moribund steelhead or if other predators fill the niche created by the removal of Caspian terns, the actual benefits of tern management will be smaller than those implied by adding predation rate estimates back in to survival estimates. Regardless, Goose Island Caspian tern predation on steelhead smolts in the Priest Rapids Project was a substantial source of mortality for smolt during outmigration and was one of, if not the single greatest, factor affecting steelhead mortality during 2008 - 2010.

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APPENDIX A.1. Recoveries of GPUD steelhead tags on bird colonies in the Columbia River basin. The number of steelhead released (N) only included those smolts used for acoustic survival studies (Skalski 2009, 2010, and 2011). Recoveries only include those smolts that were recovered in the same year they migrated (see Methods). Dashes indicate PIT tag recovery was not attempted at the island in that year. Colonies include Caspian terns (tern), California and ring-billed gulls (gull), double-crested cormorants (cormorant), American white pelicans (pelican), or a mixture of species (mix). With the exception of Banks Lake and Potholes Reservoir, all colonies are located on the Columbia River downstream of Priest Rapids Dam.

		Colony location (river kilometer) and bird species															
		Banks L.	Goose			Is. 20	Foundation	Badger	Crescent			3-mile	Blalock	Miller	East Sand Is.		
Release		(NA)	(NA)			(549)	(518)	(512)	(510)			(412)	(441)	(331)	(8)		
location	N	tern	tern	gull	mix	gull	cormorant	pelican	tern	gull	mix	gull	tern	gull	tern	cormorant	Total
Rock Island																	
2008	648	0	36	0	0	0	1	0	6	7	0	-	3	10	33	5	101
2009	797	0	47	-	0	-	0	2	8	12	0	1	2	9	32	7	120
2010	649	0	38	-	3	-	0	0	3	11	0	-	1	3	18	5	82
Wanapum																	
2008	626	0	19	1	0	1	1	0	7	7	1	-	3	8	37	3	88
2009	649	0	41	-	0	-	0	1	4	8	0	2	3	7	29	6	101
2010	650	1	23	-	1	-	0	1	2	25	0	-	0	6	11	0	70
Priest Rapids																	
2008	605	0	20	0	0	0	0	0	5	6	0	-	5	4	33	4	77
2009	650	1	28	-	0	-	0	2	9	9	0	1	2	9	32	3	96
2010	650	0	37	-	2	-	0	0	1	11	0	-	0	8	15	3	77
Total	5,924	2	289	1	6	1	2	6	45	96	1	4	19	64	240	36	812

APPENDIX A.2. Recoveries of GPUD steelhead tags on bird colonies in the Columbia River basin. The number of steelhead released (N) only included smolts used for acoustic survival studies (Skalski 2009, 2010, and 2011). Recoveries only included smolts that were not detected at or downstream of the Priest Rapids Dam acoustic detection array (i.e., removed upstream of Priest Rapids Dam) and recovered in the same year they migrated (see Methods). Dashes indicate PIT tag recovery was not attempted at the colony in that year. Colonies include Caspian terns (tern), California and ring-billed gulls (gull), double-crested cormorants (cormorant), American white pelicans (pelican), or a mixture of species (mix). With the exception of Banks Lake and Potholes Reservoir, all colonies are located on the Columbia River downstream of Priest Rapids Dam.

		Colony location (river kilometer) and bird species															
		Banks L. (NA)	Goose (NA)			Is. 20 (549)	Foundation (518)	Badger (512)	Crescent (510)			3-mile (412)	Blalock (441)	Miller (331)	East Sand Is. (8)		
Release location	N	tern	tern	gull	mix	gull	cormorant	pelican	tern	gull	mix	gull	tern	gull	tern	cormorant	Total
Rock Island																	
2008[a]	648	0	24	0	0	0	0	0	1	2	0	-	0	1	4	2	34
2009	797	0	34	-	0	-	0	0	0	0	0	0	0	0	0	0	34
2010	649	0	21	-	1	-	0	0	0	1	0	-	0	0	0	0	23
Wanapum																	
2008[a]	626	0	11	1	0	0	0	0	0	0	0	-	0	1	0	1	14
2009	649	0	15	-	0	-	0	0	0	0	0	0	0	0	0	0	15
2010	650	0	9	-	0	-	0	0	0	0	0	-	0	0	0	0	9
Priest Rapids[b]																	
2008[a]	605	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	NA	NA	NA	NA	NA
2009	650	NA	NA	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2010	650	NA	NA	-	NA	NA	NA	NA	NA	NA	NA	-	NA	NA	NA	NA	NA
Total	5,924	0	114	1	1	0	0	0	1	3	0	0	0	2	4	3	129

[a] High acoustic tag failure rates in 2008 (Skalski et al. 2009) may bias reach-specific designations, as evident by the larger number of tag recoveries downstream of Island 20 in the mainstem Columbia River in 2008 relative to 2009 and 2010.

[b] Recoveries only included steelhead removed upstream of Priest Rapids Dam; steelhead released in the Priest Rapids Dam tailrace were not available in this section.

APPENDIX A.3. Recoveries (R) of GPUD tagged steelhead on Goose Island, Potholes Reservoir separated by the presence or absence of steelhead fin clips. All fish with clipped adipose fins were of hatchery origin, while fish without fin clips were a mixture of hatchery and wild smolts (unknowns). Releases (N) only included smolts used for survival studies (Skalski 2009, 2010, and 2011). Recoveries only included smolts that were recovered in the same year they migrated (see Methods).

Release / Rearing[a]	N	R	Percent recovered
Rock Island Tailrace			
2008			
Hatchery	498	31	6%
Unknown	150	5	3%
2009			
Hatchery	562	30	5%
Unknown	235	17	7%
2010			
Hatchery	368	22	6%
Unknown	281	16	6%
Wanapum Tailrace			
2008			
Hatchery	475	13	3%
Unknown	151	6	4%
2009			
Hatchery	419	32	8%
Unknown	230	9	4%
2010			
Hatchery	403	15	4%
Unknown	247	8	3%
Priest Rapids Tailrace			
2008			
Hatchery	443	17	4%
Unknown	162	3	2%
2009			
Hatchery	409	19	5%
Unknown	241	9	4%
2010			
Hatchery	374	25	7%
Unknown	276	12	4%

[a] Unknown rearing type comprised of both unclipped hatchery reared smolts and unclipped wild smolts.