Predation of Lost River and Shortnose Suckers by Piscivorous Colonial Waterbirds in the Upper Klamath Basin: An Analysis of Predation Effects in 2024

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ABSTRACT

The recovery of endangered fish requires an understanding of the sources of mortality that regulate population dynamics. We estimated avian predation rates on passive integrated transponder tagged (PIT) adult and juvenile Lost River Suckers (*Deltistes luxatus*), Shortnose Suckers (*Chasmistes brevirostris*), Klamath Largescale Suckers (*C. snyderi*), and juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) by breeding colonies of American White Pelicans (*Pelecanus erythrorhynchos)*, Double-crested Cormorants (*Nannopterum auritum)*, Caspian Terns (*Hydroprogne caspia)*, California Gulls (*Larus californicus*), Ring-billed Gulls (*L. delawarensis*), Great Blue Herons (*Ardea herodias*), Great Egrets (*A. alba*), and Black-crowned Night Herons *(Nycticorax nycticorax)* in the Upper Klamath Basin (UKB) in 2024. Results from 2024 contribute to a long-term (2009–2023) avian predation dataset in the UKB. The largest numbers of pelicans (1,422 breeding adults), terns (610 adults), and gulls (3,872) were nesting on islands in Clear Lake Reservoir. The largest number of cormorants (787 adults) were on an island in Sheepy Lake, and the largest numbers of herons (450 adults) were at arboreal sites adjacent to Upper Klamath Lake. Predation rate estimates in 2024 were highly variable depending on the fish species, age-class (juvenile, adult), waterbody (Upper Klamath Lake, Clear Lake Reservoir, Sheepy Lake, Tule Lake), and release or reencounter date for juveniles (spring/summer or fall/winter). Results indicated that avian predation rates were the highest on wild and hatchery juvenile suckers. An estimated 19.4% (95% credible interval = 15.7–24.0) of Sucker Assisted Rearing Program (SARP) hatchery fish, released or reencountered during the spring and summer, were consumed by the colonies included in the study. Predation was also appreciable on wild juvenile suckers in Clear Lake Reservoir (13.4% [9.9–17.7]) and SARP juvenile suckers released or reencountered in Upper Klamath Lake in the fall/winter (11.2% [9.6 – 13.2]). Predation rate estimates on adult suckers were significantly lower than those of juvenile suckers, with predation ranging from 0.3% (0.2–0.7) to 2.6% (1.9–3.5) in adult Lost River Suckers in Upper Klamath Lake and adult Shortnose Suckers-Klamath Largescale Suckers in Clear Lake Reservoir, respectively. Predation rate estimates on juvenile Chinook Salmon, which were released in fall/winter, were 2.9% (2.2–3.6). Pelican (312 adults) and cormorant (301 adults) colonies in Upper Klamath Lake, however, were not scanned for fish PIT tags following breeding season, resulting in minimum estimates of predation on UKB fishes (both suckers and Chinook Salmon) in 2024. Future research could examine what biotic and abiotic factors best explain variation in predation and to what degree predation limits sucker survival using the long-term dataset that has been complied to date.

INTRODUCTION

Previously published research indicated that predation by piscivorous colonial waterbirds in the Upper Klamath Basin (UKB) was a source of mortality for Endangered Species Act (ESA) listed Lost River Suckers (*Deltistes luxatus*) and Shortnose Suckers (*Chasmistes brevirostris*) (Evans et al. 2022). Several species of piscivorous colonial waterbirds nest in the UKB, with breeding colonies of American White Pelicans (*Pelecanus erythrorhynchos)*, Double-crested Cormorants (*Nannopterum auritum)*, Caspian Terns (*Hydroprogne caspia)*, California Gulls (*Larus californicus*), Ring-billed Gulls (*L. delawarensis*), Great Blue Herons (*Ardea herodias*), Great Egrets (*A. alba*), and other native species (Shuford 2010, Evans et al. 2022). Historical accounts indicate that Lost River and Shortnose suckers were once extremely abundant but that spawning populations of both species have declined by more than 80% since the early 2000s in Upper Klamath Lake (Rasmussen 2011, Hewitt et al. 2018, Krause and Paul-Wilson 2023). Negligible recruitment into spawning populations and high juvenile sucker mortality (Burdick and Martin 2017, Hewitt et al. 2018) prompted the U.S. Fish and Wildlife Service and its partners to establish the Sucker

Assisted Rearing Program (SARP; Day et al. 2017, Day et al. 2021), a hatchery program aimed at increasing juvenile to adult survival in Upper Klamath Lake.

Recently published research indicated that predation by colonial waterbirds was the highest quantified source of sucker mortality (Evans et al. 2022). Avian predation impacts, however, were highly variable, depending on the sucker species, life stage (juvenile, adult), waterbody (Upper Klamath Lake, Clear Lake Reservoir, Sheepy Lake, Tule Lake), release site, and year. For instance, annual avian predation rates (percentage of fish consumed) on passive integrated transponder (PIT) tagged suckers have ranged from 0.1% (<0.1–0.2, 95% credible interval) to 16.1% (11.6–22.4) on adult suckers, from 4.3% (0.9–13.2) to 10.5% (3.8–24.5) on wild juvenile suckers, and from 1.8% (1.3–2.3) to 59.2% (47.2–78.2) on SARP juvenile suckers during 2009–2023 (Evans et al. 2022, Banet et al. 2024a). The location and size of piscivorous waterbird breeding colonies in UKB were also highly variable depending on the bird species, colony location, and year. Collectively, results indicate that predator-prey interactions were complex and dynamic and that avian predation, although not the initial cause of sucker declines (USFWS 2012), is now a factor limiting sucker survival given the scarcity of fish in the UKB (Evans et al. 2016).

Chinook Salmon (*Oncorhynchus tshawytscha*) were historically present in the UKB. The construction of Copco 1 Dam on the Klamath River blocked migrations of anadromous fishes to the UKB in 1912. An additional three dams on the mainstem were constructed in later years without fish passage with the farthest downstream being Iron Gate Dam. Relicensing of the four mainstem Klamath River dams in the early 2000s required upstream and downstream fish passage, resulting in a settlement agreement to remove all four dams. Oregon Department of Fish and Wildlife (ODFW) established a reintroduction plan for anadromous fish in the UKB (ODFW and Klamath Tribes 2021) with experimental releases of juvenile spring-run Chinook Salmon beginning in 2022, prior to dam removal. Four dams on the Klamath River were removed in 2024 establishing a connection from the UKB to the Pacific Ocean. An analysis of avian predation during 2022 and 2023 indicated that impacts to juvenile Chinook Salmon varied by year, release timing (spring/summer, fall/winter), release location (Upper Klamath Lake, Klamath River), and age-class (subyearling, yearling), with predation ranging annually from 3.3% (2.2–5.0) to 39.5% (30.4–52.4) (Banet et al. 2024a). Estimates of predation were lower for Chinook Salmon released in Upper Klamath Lake compared with the Klamath River and for fish released in fall/winter compared with the spring/summer (Banet et al. 2024a). Releases in fall/winter, however, were limited to a single year (2023) and uncertainties regarding the behavior and survival of Chinook Salmon following release may influence the availability of fish to avian predators, so additional research was recommended (Banet et al. 2024a). We quantified avian predation impacts on suckers and Chinook Salmon using data collected in 2024 to better understand the year-to-year variation in these vital rates. Avian predation estimates are still considered minimum estimates since not all species of piscivorous birds have been studied. More specifically, the goals of this study were to identify the location and size (number of breeding individuals) of piscivorous waterbird colonies in the UKB and to estimate predation rates on different groups of PIT-tagged suckers, including SARP fish, and experimental releases of juvenile Chinook Salmon. This study is on-going, with predation research scheduled to continue through 2027 with funding from the U.S. Bureau of Reclamation.

METHODS

Herein we provide truncated methods involving piscivorous colonial waterbird surveys, the recovery of fish PIT tags on bird colonies, and the analytical framework used to calculate predation rates. A more detailed description of these methods, including predation rate model assumptions and formulations, are provided in Evans et al. (2022).

Study area – We investigated predation on PIT-tagged fish by American White Pelicans (hereafter "pelicans"), Double-crested Cormorants (hereafter "cormorants"), Caspian Terns (hereafter "terns"), California and Ring-billed gulls (collectively hereafter "gulls"), and Great Blue Herons, Great Egrets, and Black-crowned Night Herons (collectively hereafter "herons") breeding in and around Upper Klamath Lake, OR, Clear Lake Reservoir, CA, Tule Lake, CA, Klamath River, OR, and Sheepy Lake, CA, during the spring and summer of 2024 (Figure 1).

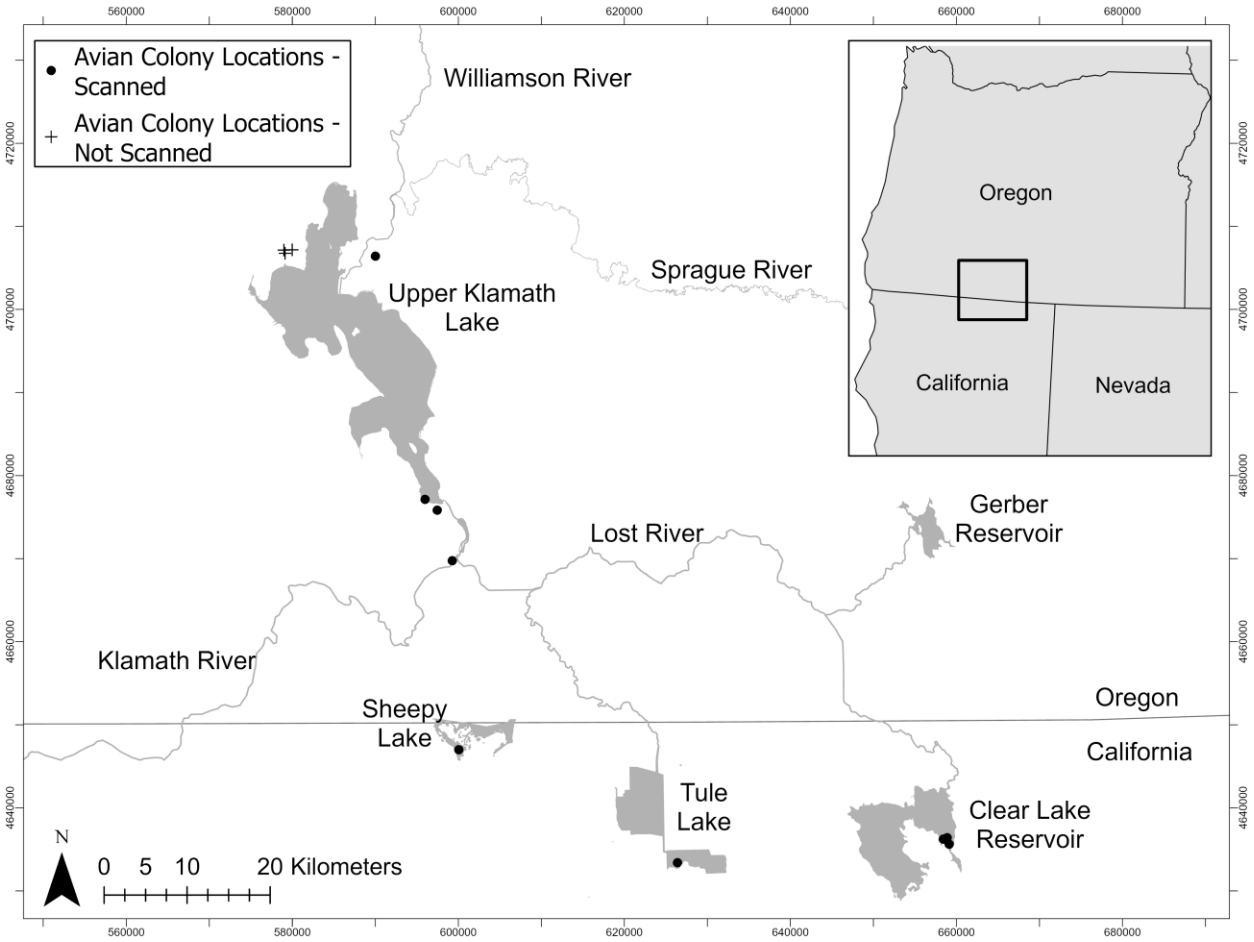

Figure 1: Location of piscivorous waterbird breeding colonies (dots) scanned for passive integrated transponder (PIT) tags implanted in fish and recovered on bird colonies in 2024. Three locations of waterbird breeding locations in Upper Klamath Marsh (crosses), two of which were new breeding sites for this study, were active in 2024 but not scanned for PIT tags.

Colony Locations and Sizes – Colony sizes were estimated based on the number of adult birds visible in oblique aerial photographs taken during the peak breeding period (May to June), with three aerial

surveys conducted of the UKB on May 7, May 28, and June 24, 2024. After the peak breeding period and in collaboration with the U.S. Fish and Wildlife Service, an additional aerial survey was conducted on August 28, 2024. Peak colony size was based on the number of adults present during the late egg incubation or early chick rearing period, the stage of the nesting cycle when the greatest number of breeding adults are found on-colony (Adkins et al. 2014). Colony size was estimated by digitizing high resolution aerial imagery at each colony and enumerating visible birds by species using ArcGIS (Environmental Systems Research Institute, Inc. 2020. ArcGIS Desktop: Release 10.8.1. Redlands, CA). Drones were also used in 2024 in a pilot study to photograph arboreal heron rookeries. This was an effort to compare the aerial image quality of drones to that of fixed-wing aircraft since these arboreal colonies prove more difficult to photograph compared to ground-based colonies. Once counts of breeding birds were complete for all surveys, maps were made that delineated the largest nesting area to the avian species (pelican, cormorant, tern, gull, and heron), which identified where to scan for PIT tags. Photos and maps of non-breeding areas (e.g., loafing or roosting sites) where large concentrations of piscivorous waterbirds congregated, were also used to identify additional areas to scan for PIT tags.

Availability of PIT-tagged Fish – The number of suckers available to birds on breeding colonies in 2024 were based on the number of PIT-tagged fish released or reencountered (previously tagged) between September 1, 2023, and August 31, 2024 (see also Evans et al. 2016). Fish that were not reencountered could be either dead or alive, so only known releases or reencounters were included in the study. Adult suckers were identified to species, Lost River Sucker (hereafter "LRS"), Shortnose Sucker (hereafter "SNS"), and Klamath Largescale Sucker (hereafter "KLS"), measured (fork-length; mm), and PIT-tagged (12-mm [length] × 2-mm [width], 134 kHz, full-duplex, *Biomark, Merck Animal Health*). In keeping with recent research showing a lack of genetic distinctiveness between SNS and KLS in Clear Lake Reservoir (Dowling et al. 2016, Smith et al. 2020, USFWS 2023a), individuals that were identified as either SNS or KLS were combined into a single "SNS-KLS" species designation. Juvenile suckers were defined as individuals < 300 mm fork-length based on age and growth information (Terwilliger et al. 2010) and observations of the smallest individuals that joined spawning migrations (Hewitt et al. 2018). Wild juvenile suckers up to age-2 cannot be accurately identified to species in the field (Burdick and Martin 2017). Releases and re-encounter histories of wild juveniles and adult suckers in Upper Klamath Lake and Clear Lake Reservoir were provided by the U.S. Geological Survey (USGS) Western Fisheries Research Center – Klamath Falls Field Station. Releases and re-encounter histories of SARP juveniles into Upper Klamath Lake during the availability period in 2024 were provided by the U.S. Fish and Wildlife Service – Klamath Falls Field Office (USFWS 2025). Releases and reencounters of SARP fish occurred during fall/winter (September 1, 2023, to February 29, 2024) or the spring/summer (March 1, 2024, to August 31, 2024). Release timing and year does not always coincide with season assignment. For example, a SARP fish released in October 2023 that was reencountered on a PIT-tag array in April 2024 would be assigned as a spring/summer SARP fish. SARP fish released or reencountered in prior availability years were also included in this analysis and assigned to fall/winter or spring/summer depending on rencounter season. Release histories of juvenile Chinook Salmon into Upper Klamath Lake and tributaries of Upper Klamath Lake occurred in the fall/winter. In addition to PIT-tags, radio telemetry tags and acoustic tags were also inserted into some suckers, but since these fish were tagged, handled, and released in a different way than PIT-tagged only fish, double-tagged fish were not included in this analysis, nor were they included in Evans et al. (2022) or Banet et al. (2024a). Finally, although not the primary focus of this study, other groups of experimental suckers (e.g., Klamath Tribes Fish Hatchery, USFWS Lower Klamath National Wildlife Refuge ponds, juvenile rehabbed suckers, juvenile

suckers released from net pens, and SARP suckers released at Lakeside Farms) were also PIT-tagged in the UKB and analyzed as part of this study (Krause et al. 2022, USFWS 2025). Data and results regarding these experimental groups are reported separately in Appendix B, Table B.1 and Table B.2.

PIT Tag Recovery – Fish PIT tags consumed by birds and deposited on their nesting colony were detected *in situ* after birds dispersed from colonies following the breeding season (September to November). An exception to this was for the Black-crowned Night Heron colony on the Klamath River that had never been scanned prior to 2024. This colony was also scanned on April 17, 2024, to detect tags deposited from prior breeding seasons. Electronic detections were recorded using hand-held PIT tag antennas and transceivers (Evans et al. 2022). PIT tags were detected by scanning the entire area occupied by birds during the breeding season, with two passes or complete sweeps of the breeding site conducted each year. Areas were scanned by individual avian species (cormorant, pelican, gull, tern, heron) when possible or as mixed or co-nesting breeding sites (see also Evans et al. 2022). Scans of non-breeding (loafing, roosting) sites were also conducted. Tags detected at loafing/roosting sites were indirectly incorporated in predation rates through PIT-tag deposition probabilities in the model (see Predation Rates for details). Tags from avian loafing/roosting sites also provide information to fisheries managers interested in the fates of tagged fish. Finally, although colonies of cormorants and pelicans were present in Upper Klamath Lake (see *Results*), they were not scanned for PIT tags following the 2024 breeding season because the amphibious vessel necessary to access the site, a Marsh Master® (Coast Machinery, LLC), was not available for use.

Predation Rates – A hierarchical Bayesian model was used to estimate predation probabilities or rates (percentage of fish consumed) on suckers and Chinook Salmon based on the number of PIT-tagged fish available and the number of tags recovered on bird colonies (Evans et al. 2022). The probability of recovering a PIT-tag on a bird colony was the product of three stochastic processes: (1) the probability that a tagged fish was consumed (predation probability), (2) the probability that the tag was deposited on the colony (deposition probability), and (3) the probability that the tag was detected by researchers following the breeding season (detection probability). PIT-tag detection probabilities were estimated by depositing or sowing tags with known tag codes on colonies to model detection probabilities throughout the breeding season using logistic regression (see Evans et al. 2022 and Appendix A, Table A.2). PIT-tag deposition probabilities for pelicans, terns, cormorants, and gulls were based on results of previously published studies that fed PIT-tagged fish to breeding birds of each species from multiple colonies. The average annual proportion of known ingested tags that were subsequently deposited on-colony were then used to estimate predator-specific deposition probabilities (see Evans et al. 2022, and Appendix A, Table A.3). No previously published PIT tag deposition probability estimate, however, was available for heron colonies. In lieu of empirical data, the average annual estimate from pelicans and cormorants, the two species that most closely resemble herons in terms of their size (mass) and ability to potentially consume large-sized prey items, were used. The validity of this assumption, however, is untested, so predation rate estimates by heron colonies should be interpreted cautiously (Banet et al. 2024a).

Predation rate models were run using the software STAN (Stan Development Team 2020), accessed through R version 4.1.0 (R Development Core Team 2014). Predation rate estimates represent simulated posterior medians with 95% highest (posterior) density intervals (95% Credible Interval). To avoid imprecise results that can occur with small sample sizes of PIT-tagged fish, predation rates were limited to groups of fish with > 100 PIT-tagged individuals (Evans et al. 2022). In cases where no (zero) PIT tags

from a given group of fish were recovered on a bird colony, estimates are presented as < 0.1%, the lowest reportable estimate (Evans et al. 2012).

RESULTS AND DISCUSSION

Bird Colony Locations and Sizes – Colonial waterbirds generally arrive to nest in the UKB in March and remained on-colony until August (Evans et al. 2016, Banet et al. 2024a). In 2024, colony surveys indicated that the number of pelicans (individual adults) counted on all breeding sites in UKB was 2,036, with the largest colony located in Clear Lake Reservoir (1,422 adults; Table 1). The total number of cormorants counted at all breeding sites was 1,270, with the largest colony located on Sheepy Lake (787 adults; Table 1). Pelicans and cormorants nested on islands with diverse habitat types, including tule marsh in Upper Klamath Lake, open bare substrate on Sheepy Lake, and rocky substrate on Clear Lake Reservoir. Terns had colonies exclusively on bare substrate habitats at Clear Lake Reservoir (610 adults), Sheepy Lake (154 adults), and Tule Lake (73 adults; Table 1). A total of 479 adult herons were counted at all breeding sites combined, with the vast majority located at tree-nesting or arboreal rookeries in and around Upper Klamath Lake (450 adults; Table 1). In another arboreal rookery along the Klamath River, a total of 140 Black-crowned Night Herons were counted. The most abundant species were gulls, with 9,527 adults counted at all breeding sites combined, with the largest colonies located at Sheepy Lake (3,611 adults) and Clear Lake Reservoir (3,872 adults; Table 1).

Counts of piscivorous colonial waterbirds during 2021–2023 are provided in Appendix A, Table A.1 (see Evans et al. 2016 and Evans et al. 2022 for counts dating back to 2009). Counts of pelicans and cormorants from 2024 were similar to or higher than those observed in years past, with the largest pelican colonies generally found on islands in Clear Lake Reservoir and the largest cormorant colonies on islands in Upper Klamath Lake and Sheepy Lake. There was some evidence that the size of the cormorant colony on Sheepy Lake is increasing, with counts from 2023 (680 adults) and 2024 (787 adults) being the largest observed since the island was built by the U.S. Army Corps of Engineers in 2010. For terns, counts have been highly variable depending on the site (Sheepy Lake, Tule Lake, Clear Lake Reservoir) and year, with less than 100 adults to upwards of 775 adults counted at some sites and years. Tern counts in 2024 were the highest in Clear Lake Reservoir (610 adults), a location where larger numbers of terns have been observed in recent years (Roby et al. 2021, Banet et al. 2024a), and new tern colonies were observed at Clear Lake in every aerial survey in 2024 including the one in August. Counts of heron and gull colony sizes were not available until 2023, so trends over time are lacking.

In 2023 and 2024, multiple aerial surveys were conducted over the course of the breeding season, which provided the most accurate colony counts and delineations of areas to scan for PIT tags (Banet et al 2024). Conversely, a single aerial survey was conducted in some past years (e.g., in 2021 and 2022), which provided limited information on nesting chronology, when and if colonies failed or successfully fledged young, and how the colony area changed over the course of the breeding season. For instance, cormorant and pelican nesting sites in Upper Klamath Lake failed at some point during the 2021 breeding season prior to the June aerial survey. Since no birds were present at the time of the June survey, counts of colony size were not available and delineating exact colony areas to scan for PIT tags was a best guess based on what appeared to be failed nesting sites (Banet et al. 2024a). In 2024, an aerial survey in August also provided additional information on new colonies not identified in previous May and June surveys, specifically in Clear Lake for Caspian terns. As such, multiple aerial surveys are

recommended in all future years as the best method to identify colony locations that are dynamic and that change with variable water conditions in high desert ecosystems (Banet et al. 2024a).

Table 1. Peak numbers of American White Pelicans (Pelicans), Double-crested Cormorants (Cormorants), Caspian Terns (Terns), California and Ring-billed gulls (Gulls), and Great Blue Herons, Great Egrets, and Black-crowned Night Herons (Herons) by nesting location (Upper Klamath Lake, Clear Lake Reservoir, Sheepy Lake, Klamath River, and Tule Lake) in 2024. Counts during 2021–2023 are reported in Appendix A, Table A.1. See Evans et al. 2016 and 2022 for counts dating back to 2009.

Nesting Location	Species	No. Counted
Upper Klamath Lake [1]	Pelicans	312
	Cormorants	301
	Herons	450
Clear Lake Reservoir [2]	Pelicans	1,422
	Cormorants	182
	Herons	29
	Terns	610
	Gulls	3,872
Sheepy Lake	Pelicans	302
	Cormorants	787
	Terns	154
	Gulls	3,611
Klamath River	Herons	140
Tule Lake	Pelicans	-
	Cormorants	-
	Terns	73
	Gulls	2,044

[1] Nesting by cormorants, pelicans, and herons occurred at multiple sites within and around Upper Klamath Lake.
[2] Nesting by cormorants, pelicans, terns, gulls, and herons occurred at multiple sites in Clear Lake Reservoir.

Availability of PIT-tagged Suckers and Chinook Salmon – The numbers of released or re-encountered PIT-tagged adult LRS, SNS, KLS, and SNS-KLS varied considerably by species and waterbody (Upper Klamath Lake, Clear Lake Reservoir). Sample sizes of PIT-tagged adult LRS and SNS in Upper Klamath Lake were 5,212 and 2,627 tagged fish, respectively (Table 2). Due to differences in population demographics, variable reservoir conditions, and sampling methods, the sample sizes of adult LRS in Clear Lake Reservoir were smaller than those in Upper Klamath Lake at 2,149 adults (Table 2, Hewitt et al. 2021). Relatively large number of adult SNS-KLS suckers were available in Clear Lake Reservoir, with 4,862 tagged adults identified (Table 2). Although KLS are not targeted specifically in sampling efforts of LRS and SNS, KLS have been PIT-tagged in previous years. Sample sizes of adult KLS in Upper Klamath Lake were 736 tagged fish in 2024 (Table 2). Overall, the numbers of tagged adult suckers in the UKB in 2024 were lower than those in years past, which can be attributed, in part, to population declines (Krause and Paul-Wilson 2023). For instance, Evans et al. (2016) reported sample sizes of more than 20,000 and 6,000 tagged LRS and SNS, respectively, in Upper Klamath Lake annually during 2010–2014.

Numbers of PIT-tagged SARP juveniles released and reencountered in Upper Klamath Lake and its tributaries ranged from 1,142 during the spring/summer to 6,537 during the fall/winter period (Table 2). Fish available during the fall/winter period were presumably not susceptible to predation by breeding piscivorous waterbirds during fall/winter. Conversely, SARP fish available in the spring/summer period were presumably susceptible to predation by breeding colonies immediately following their release or reencounter. We assumed negligible winter natural mortality for SARP fish released and reencountered in the fall/winter, but any substantial mortality can reduce the number of fish available as prey to colonial waterbirds during the breeding season and could bias estimates of predation low (see also Predation Rates *below*).

Numbers of PIT-tagged wild juveniles in Upper Klamath Lake (n=62) were too small to generate reliable predation estimates (see Methods). Adequate numbers of wild juveniles, however, were available in Clear Lake Reservoir in 2024 (n=818; Table 2). Apart from Clear Lake in 2024, numbers of wild juveniles available for predation analysis have been < 220 PIT-tagged fish in all years dating back to 2009, with only 100 or more wild juveniles available in 7 of the last 15 years (Banet et al. 2024a). Despite extensive efforts to sample wild juveniles, low catch rates of taggable fish have been documented since long-term monitoring of juvenile sucker populations began in 2015 (Martin et al. 2024). While higher catch rates of juvenile suckers are typically more common in Clear Lake, suckers may be too small and/or temperatures too warm for tagging wild suckers.

A total of 9,156 PIT-tagged hatchery juvenile Chinook Salmon were released into Upper Klamath Lake and its tributaries during the fall/winter period and considered to be subyearling (fish <1 year of age, Table 2). In 2022 and 2023, Chinook Salmon were also released in the spring/summer, and some fish were released directly into the Klamath River (see Banet et al. 2024a for additional information).

Table 2. Numbers of passive integrated transponder (PIT) tagged adult Lost River Suckers (LRS), Shortnose Suckers (SNS), Klamath Largescale Suckers (KLS), SNS-KLS, juvenile suckers (wild and Sucker Assisted Rearing Program {SARP}), and juvenile Chinook Salmon available and subsequently recovered on piscivorous waterbird colonies in Upper Klamath Lake (UKL), Clear Lake Reservoir (CLR), Sheepy Lake (SL), Klamath River (KR), and Tule Lake (TL) in 2024. Releases or reencounters of juvenile SARP suckers and juvenile Chinook Salmon occurred during the spring/summer (Spr/Sum; March 1, 2024 – August 31, 2024) or fall/winter (Fall/Win; September 1, 2023 – February 29, 2024). Recoveries represent the total number of suckers consumed from all bird colonies nesting at sites within each waterbody (UKL, CLR, SL, TL). Tag recoveries only include those tags that were recovered on breeding colonies the same year the fish was determined to be available to avian predators, and the number was not adjusted to account for detection or deposition probabilities and thus represents minimum numbers of consumed tagged fish each year (see Methods).

			No. Recovered on Bird Colonies				
Location [1]	Fish Group [2]	No. Available	UKL [3]	CLR	SL	KR	TL
Upper Klamath Lake	Adult LRS	5,212	-	7	-	-	-
	Adult SNS	2,627	-	22	5	-	-
	Adult KLS	736	-	2	1	-	-
	Juvenile suckers (Wild)	62	-	1	-	-	-
	Juvenile suckers (SARP–Spr/Sum)	1,142	49	10	25	-	-
	Juvenile suckers (SARP–Fall/Win)	6,537	100	23	121	1	1
	Juvenile Chinook (Fall/Win)	9,156	4	16	81		1
Clear Lake Reservoir	Adult LRS	2,149	-	5	-	-	-
	Adult SNS-KLS	4,862	-	51	1	-	-
	Juvenile sucker (Wild)	818	-	58	1	-	1

[1] PIT tags recovered from multiple nesting sites within each waterbody; see also Figure 1.
[2] Unidentified suckers (adults or juveniles of unknown origin), suckers salvaged/rehabbed from canals, used in net pen experiments, released at Lakeside Farms, reared in Lower Klamath National Wildlife Refuge ponds, released by The Klamath Tribes, or double-tagged (PIT, radio/acoustic) were excluded; see Appendix B for details.
[3] Pelican and cormorant colonies in Upper Klamath Lake (see Table 1) were not scanned following the breeding season in 2024.

PIT Tag Recovery – For available adult suckers, PIT tags from 3 KLS, 7 LRS and 27 SNS from Upper Klamath Lake and 5 LRS and 52 SNS/KLS from Clear Lake Reservoir were recovered on bird colonies in 2024 (Table 2). No PIT tags from available adult suckers were recovered from bird colonies on Tule Lake in 2024. For wild juvenile suckers, 1 PIT tag from an Upper Klamath Lake sucker was recovered, while 58 PIT tags from wild juveniles in Clear Lake were recovered on bird colonies (Table 2). For SARP suckers released or available in Upper Klamath Lake during fall/winter period, 246 tags were recovered on bird colonies (Table 2). For SARP suckers released or available in Upper Klamath Lake during the spring/summer period, 84 tags were recovered (Table 2). A total of 102 PIT tags from juvenile Chinook Salmon released into Upper Klamath Lake in fall/winter period were recovered on bird colonies (Table 2). Appendix A, Table A.4 provides information on the total number of sucker PIT tags recovered on bird colonies and avian loafing/roosting sites throughout the UKB, regardless of the year the tag was consumed (2009–2024) and deposited by a bird (see also Evans et al. 2022).

A total of 380 PIT tags were newly recovered at loafing sites during 2024. While scans of loafing sites typically result in low numbers of new tag recoveries and are not scanned every year or with the same frequency as breeding locations, recent efforts have identified a few key locations. Loafing sites in Agency Lake, where large numbers of piscivorous waterbirds were observed in aerial surveys in 2024, continue to be important tag recovery locations resulting in over 250 newly recovered tags. A new scanning location in 2024, a peninsula at the Klamath Falls water treatment facility, detected 99 newly recovered tags. While tags recovered at loafing sites were not used in predation analyses, future studies could incorporate these tag recoveries in models that jointly estimate predation and survival (Payton et al. 2019). As such, scanning loafing sites, such as those in Agency Lake and the water treatment facility, within the breeding season of piscivorous birds, could lead to a better understanding of avian predation and sucker mortality across space and time.

At the time of this report, there were 295 PIT tags from unknown-origin fish recovered on bird colonies in 2024. Some tags were from suckers where the species and/or age-class were unknown at the time of release. Unknown tags may also be from agencies within and outside of the UKB that have not shared release records of fish on individual projects. The number of unknown tag recoveries in 2024 was higher than any other year. This may be due to scanning new areas (more effort) and being associated with differences in release strategies of fish in Upper Klamath Lake and nearby water bodies. A total of 59 recovered tags were identified after the analyses had been completed and excluded from summaries in this report.

There were 30 newly recovered salmonid PIT tags, originally tagged in the Columbia River basin, that were detected on UKB avian colonies in 2024. Of these, 11 were from Steelhead Trout (*O. mykiss*) and 19 were from Chinook Salmon from original release sites ranging from the Deschutes River basin to the Upper Salmon River in Idaho. Two Klamath Redband Trout (*O. mykiss newberrii*) tags from the UKB were also recovered in 2024.

Predation Rates – Estimated cumulative predation rates (predation by all colonies scanned for tags combined) on adult LRS, KLS, and SNS suckers from Upper Klamath Lake were low at 0.3% (0.2–0.7), 1.2% (0.4–2.9), and 2.6% (1.7–3.8), respectively, in 2024 (Table 3). Estimated cumulative predation rates on adult LRS and SNS/KLS from Clear Lake Reservoir were similar to or higher than those of suckers in Upper Klamath Lake at 0.6% (0.2–1.3) and 2.6% (1.9–3.5), respectively (Table 3). Estimates of predation on LRS and SNS-KLS suckers from Clear Lake Reservoir were higher than those observed in adult suckers from Upper Klamath Lake in most years dating back to 2009 (Appendix A, Table A.5). The exact reason for higher predation impacts on adult suckers from Clear Lake Reservoir is unknown. Higher predation risks in Clear Lake Reservoir may be attributed to larger colonies of piscivorous waterbirds or by abiotic conditions in the reservoir, like lake surface elevation and water management (Hewitt et al. 2021). Avian predation has also been documented in sucker spawning tributaries in Clear Lake (Banet et al. 2021). This was also documented in the current study with PIT detections of three Lakeside Farms SARP suckers being detected on the Willow Creek PIT-tag arrays, tags that were inside avian predators and within detection range of the Willow Creek array. In the case of predation on adult LRS and SNS from Upper Klamath Lake, annual estimates of predation in years past were similar to those observed during 2009–2023, with annual estimates often < 2% of available fish and no more than 3.7% of available fish (Appendix A, Table A.5). Since pelican and cormorant colonies in UKL were not scanned for tags following the breeding season in 2024, estimate of predation reported herein are minimums, so

comparisons of predation in 2024 to years past (2009 – 2023), particularly those on UKL suckers, should be interpreted cautiously.

Table 3. Estimates of predation rates (95% credible intervals) on PIT-tagged adult Lost River Suckers (LRS), Shortnose Suckers (SNS), Klamath Largescale Suckers (KLS), and Shortnose/Klamath Largescale Suckers (SNS-KLS) by piscivorous colonial waterbirds nesting at colonies in Upper Klamath Lake, Clear Lake Reservoir, Sheepy Lake, Tule Lake, and Klamath River in 2024. Predation estimates are adjusted to account for PIT tag detection and deposition probabilities that were unique to each predator species, colony, and year.

	Upper Klamath Lake [1]			Clear Lake Reservoir	
Year	Adult LRS	Adult KLS	Adult SNS	Adult LRS	Adult SNS-KLS
2024	0.3% (0.2–0.7)	1.2% (0.4–2.9)	2.6% (1.7–3.8)	0.6% (0.2–1.3)	2.6% (1.9–3.5)

[1] Pelican and cormorant colonies in Upper Klamath Lake were not scanned for PIT tags, resulting in minimum estimates of predation in 2024.

An investigation of predator- and colony-specific predation rates indicated that predation on adult LRS and SNS-KLS suckers from Clear Lake Reservoir was almost exclusively from birds nesting on islands in Clear Lake Reservoir (Figure 2). One adult SNS-KLS from Clear Lake was recovered on Sheepy Lake. Conversely, predation on adult suckers from Upper Klamath Lake were from birds nesting on islands in Upper Klamath Lake, Clear Lake Reservoir, and Sheepy Lake (Figure 2). These results are consistent with those of Evans et al. (2016, 2022) and Banet et al. (2024a) and suggest foraging conditions for birds nesting on islands in Clear Lake Reservoir and Sheepy Lake may be sub-optimal or inadequate in some years, with birds from these locations commuting longer distances (greater than 30 km) to forage on fish in adjacent waterbodies. Despite foraging by multiple predator species and colonies on adult suckers from Upper Klamath Lake, cumulative and colony-specific predation rates on adult suckers were low in 2024 and in most, but not all, years past. Again, however, estimates in 2024 are minimums because pelican and cormorant colonies in UKL were not scanned for PIT tags. Total numbers of pelicans and cormorants breeding in Upper Klamath Lake colonies were similar or higher compared to 2021-2023 (Banet et al. 2024a) but lower compared to 2018 – 2020 (Evans et al. 2021). Previous research indicated that predation by cormorant and pelican colonies nesting on islands in Upper Klamath Lake were the highest on adult suckers from Upper Klamath Lake (Evans et al. 2016, 2022), so results on the cumulative effects of avian colonies on Upper Klamath Lake suckers in 2024 should be interpreted cautiously.

Of the predator species evaluated, predation on adult suckers was predominantly or exclusively by pelicans and cormorants (Figure 2). Conversely, predation on adult suckers by herons was low (< 0.2%) and was only observed on adult Shortnose and Klamath Largescale suckers. These results are consistent with those from 2023, the first-year heron colonies were scanned for sucker PIT tags (Banet et al. 2024a). No adult suckers were consumed by Black-crowned Night Herons in the first year this avian predator species was studied, and these species might also be limited to prey sizes similar to that of terns and gulls. There also appeared to be limited or no predation on adult Clear Lake suckers from terns and gulls in 2024 (Figure 2). These species are limited to prey that are < 300 mm in size (Hostetter et al. 2023, Banet et al. 2024a). Thus, the 13 adult sucker tags detected at tern and gull nesting areas in 2024 were likely deposited by nearby nesting cormorants and pelicans. As chicks of all species become more

mobile, traveling through other nesting areas becomes more common as the breeding season continues. With that caveat in mind, the majority of tags deposited on species-specific areas were assumed to be of that nesting species (Evans et al. 2022, Banet et al. 2024a).

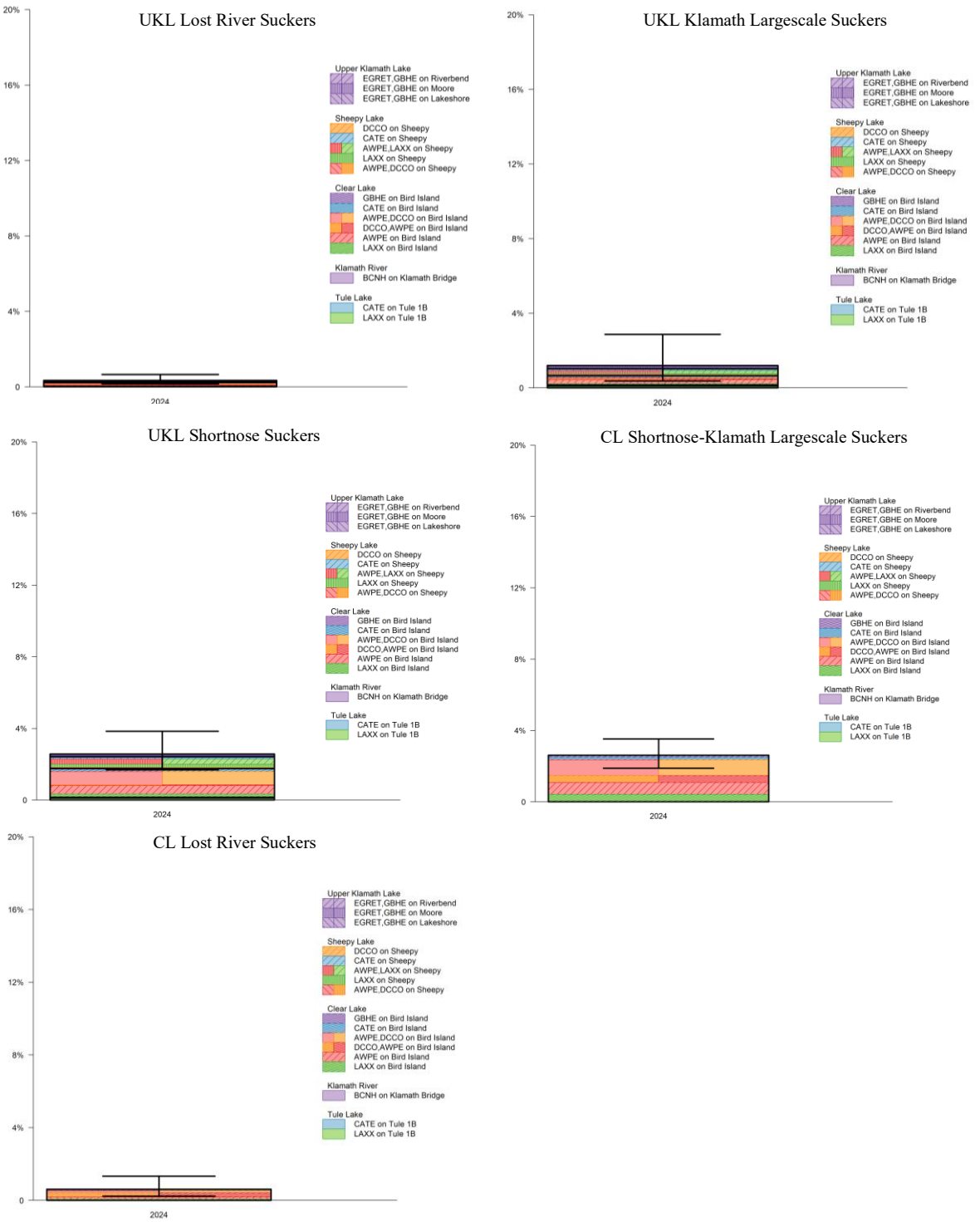

Figure 2. Estimated colony specific- and cumulative predation rates on PIT-tagged adult suckers in Upper Klamath Lake (UKL) and Clear Lake Reservoir (CL) in 2024. Avian predation species include American White Pelicans (AWPE; red-colored bars), Double-crested Cormorants (DCCO; orange-colored bars), Caspian Terns (CATE; blue-colored bars), California Gulls and Ring-billed Gulls (LAXX; green-colored bars), Great Blue Herons (GBHE; yellow-colored bars), Black-crowned Night Herons (BCNH; purple-colored bars), and Great Egrets (EGRET; purple-colored bars). Mixed species colony sites are combination of species. Error bars represent 95% credible intervals. Active pelican and cormorants in Upper Klamath Lake (see *Table 1*) were not scanned for PIT tags.

Tags from wild juvenile suckers from both Upper Klamath Lake and Clear Lake Reservoir were recovered on bird colonies in 2024 (Table 1), but samples sizes from Upper Klamath Lake were too small (< 100) to generate reliable estimates of predation. For wild juveniles in Clear Lake Reservoir, an estimated 13.4% (9.9–17.7) of available fish were consumed by the avian colonies included in the study in 2024 (Table 4). These results are consistent with those in years past and indicate that predation on wild juvenile suckers was greater than that of adult suckers, especially when making comparisons within the same waterbody and year. For instance, in 2022, an estimated 9.8% (2.8–25.4) of wild juvenile suckers in Clear Lake Reservoir were consumed by birds compared with predation estimates of < 1.0% on adult LRS and SNS-KLS in Clear Lake Reservoir (Appendix A, Table A.5). Although no comparison to wild juveniles was available, one exception may have been 2021 when predation on adult LRS in Clear Lake was 16.1% (11.6–22.4%, Banet et al. 2024a). Evans et al. (2022) theorized that due to their small size (< 300 mm) juvenile suckers are more susceptible to predation because multiple species (terns, gulls, herons, cormorants, and pelicans) consume juveniles, but that adult suckers exceed the gape width of some predator species. For instance, terns and gulls consume suckers that are < 300 mm. Cormorants have been documented to consume suckers and other fish up to ~ 450 mm (Evans et al. 2016, Hostetter et al. 2023), so some, but not all, adult-sized suckers are susceptible to cormorant predation. While herons have been documented to consume suckers up to ~ 370 mm (Banet et al. 2024a), a PIT tag from an adult KLS with a last measurement of 400 mm in March 2022 and available in 2023, was detected at the Riverbend rookery in 2024. There were only six additional sucker tags with fork lengths > 300 mm, all SARP suckers, detected at heron specific colonies. Of these, two SARP PIT tags recovered were also radio telemetry fish and were not included in this analysis of PIT-tagged only suckers. Results continue to suggest that most suckers >300 mm are rarely consumed by herons. Conversely, all but the largest adult suckers are susceptible to pelican predation. For example, PIT tags from a 730 mm and 746 mm adult LRS have been recovered on pelican colonies in the UKB in years past (Evans et al. 2016, Banet et al. 2024a). When larger sample sizes are available for length data of SARP releases, we will also be able to estimate predation on fish of a specific length. Currently, only a subset of SARP releases have length data and reencountered SARP fish are rarely physically recaptured for an updated length.

Predation rates on SARP juvenile suckers from Upper Klamath Lake that were available in the fall/winter were estimated at 11.2% (9.9–13.2) in 2024 (Table 4). Estimated predation on SARP juvenile suckers available in the spring/summer were significantly higher at 19.5% (15.4–24.6) (Table 4). Similar to results during 2022–2023, results from 2024 suggested that predation of available spring/summer SARP was approximately double that of available fall/winter SARP. Relative comparisons of predation, however, should be viewed cautiously because an unknown number of available fall/winter SARP fish presumably died prior to start of the 2024 waterbird breeding season. Thus, availability of fall/winter SARP suckers to nesting colonial waterbirds in spring/summer may be lower than the available number, which would bias predation rate estimates low. More accurate relative comparisons of predation based on seasonal availability (winter/fall, spring/summer) would require information on the survival of SARP fish in space and time, estimates that will be explored as part of this study in the coming years (see *below*). In 2023, SARP juveniles were also released in Sheepy Lake during the spring/summer period, with an estimated 59.2% (47.2–78.2) of available fish consumed by colonial waterbirds (Appendix A, Table A.5), the highest predation rate observed since studies commenced in 2009 (Banet et al. 2024a). Although no SARP suckers were released in Sheepy Lake in 2024, there were 46 newly recovered tags from 2023 Sheepy Lake releases at breeding and loafing colonies in 2024. Unlike wild juvenile suckers, samples sizes of

SARP juveniles typically include thousands of tagged fish, resulting in more precise estimates of predation. Collectively, predation estimates on juveniles indicate that avian predation is the highest known cause of mortality. To-date, SARP and wild suckers have not been documented returning to spawning grounds in sufficient numbers to augment existing spawning populations (Krause et al. 2022, Krause and Paul-Wilson 2023). Thus, strategies that minimize avian predation, like releasing SARP fish in fall/winter and/or releasing larger-sized fish to reduce predation by terns, gulls, and herons, may be paramount to increasing SARP survival in the coming years.

Estimated predation rates on juvenile Chinook Salmon released into Upper Klamath Lake in fall/winter were 2.9% (2.2–3.6) of released fish, significantly lower than those observed on fall/winter SARP juvenile releases (Table 4 and Figure 3). Although there were no spring/summer Chinook Salmon releases in 2024, predation rate estimates in 2023 on fall/winter Chinook Salmon (5.6% [2.2–13.0]) were significantly lower than those released in the spring/summer (21.6% [18.0 – 27.3]) (Banet et al. 2024a). As such, similar to SARP releases, results suggest predation impact can potentially be reduced by releasing fish in the fall/winter as opposed to the spring/summer. Given that juvenile Chinook Salmon releases in the UKB only began in 2022, however, limited data are available for comparisons of avian predation across years and different release times. Limited information is available on the behavior and survival of Chinook Salmon released in fall/winter versus spring/summer and the movement of Chinook Salmon from Upper Klamath Lake to the Klamath River (Tallman 2024). Furthermore, very little is known about avian predation on juvenile Chinook Salmon in the middle and lower Klamath River (outside of the study area presented herein), although juvenile Chinook Salmon tags were recovered at cormorant and heron colonies in Lake Shastina, CA in 2023 (Krause et al. 2022).

Table 4. Estimates of predation rates (95% credible intervals) on PIT-tagged wild juvenile suckers, Sucker Assisted Rearing Program (SARP) juvenile suckers, and juvenile Chinook Salmon (Chinook) released into Upper Klamath Lake by piscivorous colonial waterbirds nesting at colonies in Upper Klamath Lake, Clear Lake Reservoir, Sheepy Lake, and Tule Lake in 2024. Predation estimates are for fish available in the spring (Spr)/summer (Sum) or fall/winter (Win). Predation estimates are adjusted to account for PIT tag detection and deposition probabilities that were unique to each predator species colony, and year (see Methods). Dashed line (–) denotes that sample sizes of available tagged fish were fewer than 100 (see Methods).

	Upper Klamath Lake [1]				Clear Lake Reservoir
Year	Wild Juvenile Suckers	SARP Juvenile Spr/Sum	SARP Juvenile Fall/Win	Chinook Juvenile Fall/Win	Wild Juvenile Suckers
2024	–	19.4% (15.7–24.0)	11.2% (9.6–13.2)	2.9% (2.2–3.6)	13.4% (9.9–17.7)

[1] *Pelican and cormorant colonies in Upper Klamath Lake were not scanned for PIT tags, resulting in minimum estimates in 2024.*

An investigation of predator- and colony-specific predation rates indicated that SARP juveniles available in Upper Klamath Lake were consumed by birds nesting on colonies in Upper Klamath Lake, Clear Lake, Sheepy Lake, Tule Lake, and the Klamath River and that all predator species (pelicans, cormorants, terns, gulls, and herons) consumed them to varying degrees (Figure 3). Of the predator species and colonies evaluated, predation rates on SARP juveniles were the highest by herons nesting in Upper Klamath Lake, followed by cormorants, pelicans, and gulls on Sheepy Lake (Figure 3). Again, no data were available from cormorant and pelican colonies in Upper Klamath Lake, so predation estimates on SARP releases in Upper Klamath Lake should be considered minimum estimates in 2024. Approximately half of all avian-

attributed mortality on Upper Klamath Lake SARP juvenile suckers were from herons in both 2023 (Banet et al. 2024a) and 2024 (Figure 3), results that suggest juvenile suckers may be utilizing shoreline and marsh habitats since herons are almost exclusively wading predators. Until 2023, heron and gull colonies were not scanned for PIT tags, so continued and expanded effort for herons and gulls may be beneficial in the future.

An investigation of predator- and colony-specific predation rates on juvenile Chinook Salmon released in Upper Klamath Lake in fall/winter indicated that the highest predation rates were from cormorants, pelicans, and gulls nesting on Sheepy Lake (Figure 4). Conversely, predation on Chinook Salmon by herons nesting in Upper Klamath Lake was amongst the lowest observed, despite the finding the herons nesting in Upper Klamath Lake consumed an appreciable proportion of SARP juveniles in 2024. Expanded efforts scanning gull colonies also found that predation by gulls on Chinook Salmon was substantial in both 2023 and, to a lesser degree, in 2024. Behavioral differences between juvenile salmon and suckers and/or differences in the foraging range and behavior of avian predators from each colony may help explain variation in predation rates. More research, however, is needed to better understand these and other factors that influence fish susceptibility to avian predation in the UKB (see also *below*). While further study is needed when reintroduction efforts of juvenile Chinook Salmon are fully underway, results to-date (2022–2024) suggest there could be high predation rates on Chinook Salmon in the UKB before Chinook Salmon arrive at Keno Dam, especially for Chinook Salmon that are released during the colonial waterbird breeding season of March to August. A study examining Chinook Salmon experimentally released in tributaries to Upper Klamath Lake also found low survival through the lake, possibly attributed to avian predation and salmon choosing not to out-migrate (Tallman 2024).

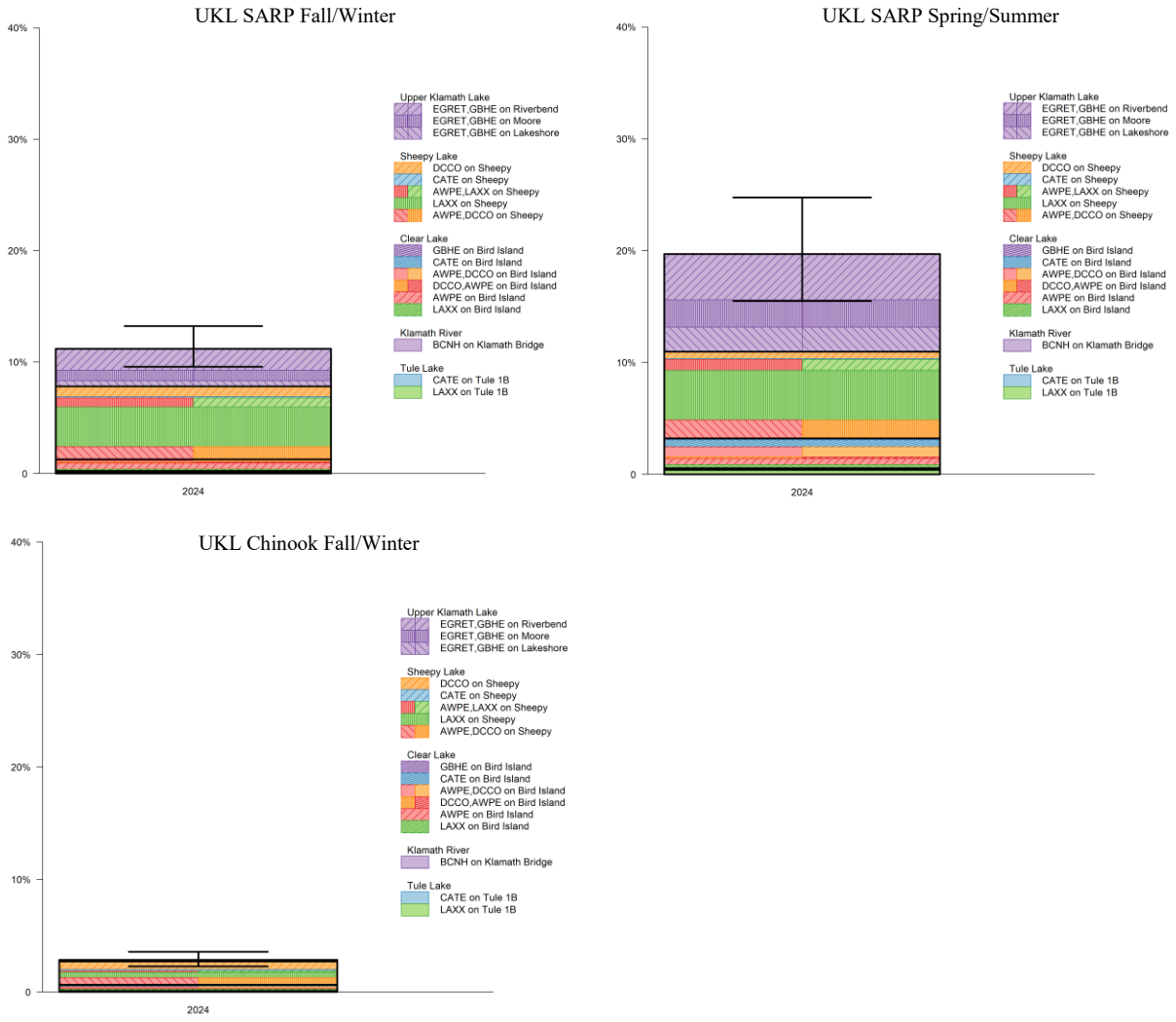

Figure 3. Estimated colony specific and cumulative avian predation rates on PIT-tagged Sucker Assisted Rearing Program (SARP) juvenile suckers and juvenile Chinook Salmon released in Upper Klamath Lake during the spring/summer and fall/winter and recovered on bird colonies in 2024. Avian species include American White Pelicans (AWPE; red-colored bars), Double-crested Cormorants (DCCO; orange-colored bars), Caspian Terns (CATE; blue-colored bars), California Gulls and Ring-billed Gulls (LAXX; green-colored bars), Great Blue Herons (GBHE; yellow-colored bars), Black-crowned Night Herons (BCNH; purple-colored bars), and Great Egrets (EGRET; purple-colored bars). Mixed species colony sites are combination of species. Error bars represent 95% credible intervals.

Prior to 2023, some gull colonies were scanned for adult sucker PIT tags, but no tags were recovered, indicating predation rates by gulls on adult suckers were low to non-existent (Evans et al. 2022). Results from 2023 and 2024 also indicate that predation by gulls on adult suckers was low to non-existent, but there is evidence that gulls are consuming SARP juveniles and juvenile Chinook Salmon. Gulls also steal (kleptoparasitism) fish from other predators that are nesting nearby, like terns on Sheepy Lake, so some unknown proportion of tagged juveniles recovered on gull colonies may have been from fish that were captured by terns and subsequently stolen by gulls (Payton et al. 2020). As such, some proportion of fish consumed by gulls were potentially dead or moribund when consumed. Estimating the size of gull colonies in the UKB, along with other target species, may assist in providing context to future predation

rates of gulls on juvenile fishes. Unlike gulls, most herons included in the study were nesting in isolation and all tags recovered from heron colonies were presumably consumed by herons, with the exception of the smaller heron colonies at Clear Lake (Table 1). Although predation by herons was low on adult suckers, an appreciable proportion of available tagged juvenile fish, especially SARP fish in Upper Klamath Lake, were consumed by herons, a group of piscivorous waterbirds that should continue to be studied in the future.

Even after accounting for predation effects by heron and gull colonies, predation rate estimates generated by this study are still minimum estimates of predation by all piscivorous waterbirds in the UKB. This is because not all piscivorous waterbird species were included in the study (e.g., Forster's Terns *Sterna forsteri*, Common Mergansers *Mergus merganser*, and grebes *Aechmophorus* spp.), and some proportion of avian predation is likely attributed to non-breeding individuals, failed breeders, and overwintering piscivorous waterbirds. For instance, herons are present in the UKB year-round, although they disperse widely from their breeding colonies in fall and winter, making predation difficult to fully quantify at heron rookeries. This study has continued investigating predation estimates by Great Blue Herons and Great Egrets for a second consecutive year and Black-crowned Night Herons for the first year of this project, leading to an expansion of the number of avian species studied in 2024. Pelicans and cormorants may also arrive in the UKB before the breeding season commences and remain in the region after the breeding season ends to forage on fish. To help better understand the movement and foraging behavior of piscivorous waterbirds in the UKB, a pilot study was performed in 2024 which tagged five cormorants and five pelicans with species specific GPS-GSM transmitters. Preliminary results documented foraging data within the Klamath Basin and migrations from the Klamath Basin to southern Mexico. Potential future research includes building on this pilot study in 2025 and 2026, data that could be used for additional analyses. Previous research using this tracking data in the Automated Interactive Monitoring System can be found in Casazza et al. (2023).

Lack of juvenile sucker recruitment in spawning populations, particularly for Upper Klamath Lake sucker populations, is an ongoing concern in the UKB. As managers continue to consider new release strategies and locations for SARP juvenile suckers, understanding known predation impacts is critical, as demonstrated by the high (ca. 59%) predation observed on SARP suckers released into Sheepy Lake in 2023 (Banet et al. 2024a). Given the investment and continued expansion of the SARP program, documenting variation in avian predation among juvenile SARP sucker releases also provides managers with critical information on the efficacy of management actions, such as knowing when and where to release fish to minimize predation effects. Given that avian predation continues to be one of the highest known causes of sucker mortality, especially among juvenile suckers, strategies to limit predation and promote survival are critical for achieving recovery goals. Recent studies found that larger release size of fish, oxygenation, and the location of net pens can improve survival of juvenile suckers (Caldwell et al. 2023, Banet et al. 2024b). Different SARP release and rearing strategies continue to evolve, and avian predation studies can inform effectiveness of these strategies (see Appendix B). As avian predation studies evolve with the SARP program, detections of live and dead fish can also be used to jointly estimate predation and survival to determine what proportion of all sources of fish mortality were due to avian predation (Payton et al. 2019). Exploring the application of these studies and to what degree biotic and abiotic factors influence sucker survival may be useful to the development of future management strategies.

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APPENDICES

Appendix A

Table A1. Peak numbers of American White Pelicans (Pelicans), Double-crested Cormorants (Cormorants), Caspian Terns (Terns), California and Ring-billed gulls (gulls), and Great Blue Herons and Great Egrets (herons) by nesting location (Upper Klamath Lake, Clear Lake Reservoir, Sheepy Lake, and Tule Lake) during 2021–2024 breeding seasons. 'NA' denotes a colony may have been active, but counts were not available. 'Active' denotes a colony that was active but not counted. Estimates reported herein are those of Banet et al. (2024a). See Evans et al. (2022) for estimates of peak colony size dating back to 2009.

Nesting Location	Species	2021	2022	2023	2024
Upper Klamath Lake [1]	Pelicans	NA [3]	97	232	312
	Cormorants	NA [3]	158 [4]	370	301
	Herons	NA	Active	574	450
Clear Lake Reservoir [2]	Pelicans	1,094 [4]	509	1,621	1,422
	Cormorants	110 [5]	114 [4]	163	182
	Terns	152 [5]	0	202	610
	Herons	Active	NA	15	29
	Gulls	Active	Active	Active	3,872
Sheepy Lake	Pelicans	169 [4]	40	239	302
	Cormorants	420 [5]	723 [4]	680	787
	Terns	324 [5]	277 [4]	290	154
	Gulls	Active	Active	Active	3,611
Tule Lake	Pelicans	338 [4]	0	0	0
	Cormorants	326 [4]	0	0	0
	Terns	0	0	0	73
	Gulls	NA	0	0	2,044

[1] Nesting by cormorants and pelicans occurred at five different nesting islands within Upper Klamath Lake.

[2] Nesting by cormorants, pelicans, terns, gulls, and herons occurred at four different sites in Clear Lake Reservoir.

[3] Although cormorants and pelicans were not present at historical nesting sites in Upper Klamath Lake at the time of the June 2021 aerial survey, nesting sites appeared to be used prior to the aerial survey and detections of current year PIT-tags indicated that colonies were active but unsuccessful at fledging young.

[4] Counts of individuals by one Real Time Research observer from photos provided by Oregon State University.

[5] Count of breeding pairs (individuals observed in nesting posture) by Oregon State University.

Table A.2. Estimated average annual detection probabilities (minimum - maximum) of PIT tags on bird colonies in Upper Klamath Lake, Clear Lake Reservoir, Sheepy Lake, and Tule Lake in 2024. Values were used to account for the proportion of sucker and Chinook PIT tags deposited by birds on their breeding colonies that were subsequently lost, damaged, or otherwise not detected by researchers. The total number of known tag codes (n) sown by researchers to model detection probabilities are also provided. 'NA' denotes data was not available for the species, at that site.

Nesting Area	Species	2024
Upper Klamath Lake	Cormorants/Pelicans	NA
	Herons	0.84 (0.81–0.95) n = 151
Klamath River	Herons	0.60 (0.54–0.87) n = 50
Clear Lake Reservoir	Cormorants/Pelicans/ Terns/Herons	0.71 (0.62–0.96) n = 215
Sheepy Lake	Cormorants/Pelicans/ Terns/Gulls	0.62 (0.47–0.98) n = 176
Tule Lake	Terns/Gulls	0.97 (0.97–0.97) n=26

Table A.3. Estimated average annual deposition probabilities (95% credible interval) of sucker PIT tags on American White Pelican (pelican), Double-crested Cormorant (cormorant), Caspian Tern (tern), California and Ring-billed Gulls (gulls), and Black-crowned Night Herons, Great Blue Herons and Great Egrets (herons) colonies in UKB. Estimates of deposition for pelicans, cormorants, terns, and gulls were those previously published by Hostetter et al. (2015) and Evans et al. (2022). Estimates for herons were derived from pelicans and cormorants (see Methods).

Species	PIT-Tag Deposition
Pelican	0.47 (0.36–0.69)
Cormorants	0.51 (0.34–0.70)
Tern	0.71 (0.51–0.89)
Herons	0.49 (0.39–0.60)
Gulls	0.15 (0.11–0.21)

Table A.4. Numbers of PIT-tagged adult Lost River Suckers (LRS), Shortnose Suckers (SNS), Klamath Largescale Suckers (KLS), and SNS-KLS Suckers and juvenile suckers, including Sucker Assisted Rearing Program (SARP) and naturally-reared (wild), recovered on bird colonies or loafing sites in the Upper Klamath Basin during 2009–2024. Numbers include all unique sucker PIT tags recovered regardless of the year the sucker was released/re-encountered, the year the tag was deposited on an avian colony, or if sucker groups had tags recovered but not analyzed for predation rates due to sample sizes being < 100. Nesting locations represent colonies of American White Pelicans, Double-crested Cormorants, Caspian Terns, California and Ring-billed Gulls, Great Blue Heron, Great Egrets and possibly other species breeding or loafing on islands within Clear Lake Reservoir, Upper Klamath Lake, Sheepy Lake, and Tule Lake. Not all nesting locations were used by birds during each breeding season, each year. Dashes (–) denote that scanning for PIT tags did not take place that year, at that site. SARP releases commenced in 2018. The number of tags was not adjusted to account for detection or deposition probabilities and thus represent minimum numbers of consumed tagged fish. Numbers were those previously reported by Evans et al. (2022) and Banet et al. (2024a).

Location [1]	Sucker Group [2]	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Clear Lake Reservoir	Adult LRS	45	18	4	42	45	29	15	7	16	16	6	9	150	19	33	28
	Adult SNS-KLS	187	57	77	159	162	111	38	111	60	64	41	43	183	39	137	119
	Juvenile (Wild)	0	0	0	4	1	0	1	0	1	1	5	7	13	8	4	63
	Juvenile (SARP)										1	0	2	34	1	35	43
Upper Klamath Lake	Adult LRS	38	1	–	72	13	29	14	–	116	136	8	5	0	3	34	14
	Adult SNS	39	–	–	68	1	25	18	–	99	83	2	2	0	1	44	24
	Juvenile (Wild)	6	0	–	8	0	1	2	–	1	0	0	0	0	0	2	0
	Juvenile (SARP)										32	50	87	26	143	470	306
Sheepy Lake	Adult LRS	1	–	–	3	0	–	–	17	11	4	3	0	8	0	3	0
	Adult SNS	2	–	–	1	0	–	–	10	13	6	3	1	0	0	3	7
	Adult SNS-KLS	0	–	–	0	0	–	–	1	0	0	0	0	0	1	0	1
	Adult KLS	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
	Juvenile (Wild)	0	–	–	0	0	–	–	2	0	0	0	7	0	0	1	1
	Juvenile (SARP)										1	12	41	103	51	286	149
Tule Lake	Adult LRS	–	–	–	–	–	1	0	0	–	0	0	0	0	–	–	0
	Adult SNS	–	–	–	–	–	0	0	0	–	0	2	0	0	–	–	0
	Adult SNS-KLS	–	–	–	–	–	1	1	3	–	0	0	1	0	–	–	0
	Juvenile (Wild)	–	–	–	–	–	0	0	0	–	6	2	0	0	–	–	2
	Juvenile (SARP)										4	1	0	0	–	–	2
Klamath River	Adult LRS	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
	Adult SNS	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0

Location [1]	Sucker Group [2]	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Klamath	Adult SNS-KLS	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
River	Juvenile (Wild)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2
	Juvenile (SARP)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	60
ALL		333	78	81	363	226	199	91	151	321	357	136	205	517	266	1,052	828 [3]

[1] PIT tags recovered from multiple nesting sites within each waterbody; see Figure 1

[2] Unidentified and undefined suckers (adults or juveniles of unknown origin), suckers salvaged from canals, used in net pen experiments or Lakeside Farms, released by Klamath Tribes Fish Hatchery, or double-tagged (PIT, radio) were excluded

[3] Pelican and cormorant colonies in Upper Klamath Lake were not scanned for PIT tags, resulting in minimum numbers of tags recovered in 2024.

Table A.5. Avian predation rates (95% credible intervals) on PIT-tagged Lost River Suckers (LRS), Shortnose Suckers (SNS), Shortnose/Klamath Largescale Suckers (SNS-KLS), and juvenile suckers by piscivorous colonial waterbirds nesting at colonies in Upper Klamath Lake, Clear Lake Reservoir, Tule Lake Sump 1B, and Sheepy Lake combined (i.e., cumulative predation effects). Predation estimates are adjusted to account for PIT tag detection and deposition probabilities that were unique to each predator species, colony, and year (see Evans et al. 2022). Dashed line (–) denotes that sample sizes of available tagged fish were fewer than 100 or that PIT tag recovery did not occur at that site in that year. NA denotes that fish were not released at that location and year. Estimates are those previously reported by Evans et al. (2022).

Year	Upper Klamath Lake					Clear Lake Reservoir		
	Adult LRS	Adult SNS	Juvenile Wild	Juvenile SARP – Spr/Sum	Juvenile SARP – Fall/Win	Adult LRS	Adult SNS/KLS	Juvenile Wild
2009	0.5% (0.3–0.9)	1.5% (1.0–2.6)	10.1% (4.8–19.3)	NA	NA	7.2% (2.8–16.4)	4.6% (2.6–8.4)	–
2010	–	–	–	NA	NA	0.7% (<0.1–3.8)	0.6% (<0.1–1.8)	–
2011	–	–	–	NA	NA	0.8% (0.1–3.2)	4.0% (2.6–7.0)	–
2012	1.1% (0.7–1.7)	3.7% (2.6–5.7)	10.0% (4.8–19.0)	NA	NA	4.7% (1.8–10.8)	3.8% (1.8–7.6)	–
2013	–	–	–	NA	NA	6.7% (3.7-12.8)	6.2% (4.0-10.2)	–
2014	0.2% (0.1–0.4)	0.9% (0.5–1.8)	–	NA	NA	2.1% (0.8–4.9)	1.8% (1.0–3.7)	–
2015	0.2% (0.1–0.3)	0.8% (0.4–1.4)	–	NA	NA	2.5% (<0.1–5.5)	1.4% (0.7–2.7)	–
2016	–	–	–	NA	NA	1.2% (<0.1-3.0)	4.0% (2.8-6.5)	–
2017	1.0% (0.7–1.8)	3.6% (2.4–5.7)	–	NA	NA	0.4% (0.1–1.5)	1.9% (1.2–3.5)	4.3% (0.9–13.2)
2018	1.0% (0.7–1.7)	2.5% (1.6–4.0)	–	4.3% (2.9–6.7)	NA	2.2% (0.9–5.0)	1.4% (0.7–2.7)	–
2019	0.2% (0.1–0.4)	0.6% (0.3–1.2)	–	5.6% (4.0–8.2)	NA	0.5% (0.1–1.7)	1.7% (1.0–3.1)	5.6% (1.5–14.7)
2020	0.1% (<0.1–0.2)	0.4% (0.2–0.9)	–	8.5% (6.3–12.7)	NA	1.2% (0.4–3.2)	2.0% (1.0–4.2)	10.5% (3.8–24.5)
2021	0.3% (0.2–0.6)	0.6% (0.3–1.1)	–	1.8% (1.3–2.3)	2.5% (1.9–3.4)	16.1% (11.6–22.4)	5.5% (3.8–7.9)	–
2022	< 0.1%	< 0.1%	< 0.1%	4.2% (3.3–5.5)	2.2% (1.4–3.4)	0.5% (0.1–1.5)	0.9% (0.4–1.9)	9.8% (2.8 –25.4)
2023	0.8% (0.5–1.3)	2.6% (1.8–3.9)	–	19.7% (16.6–23.3)	9.8% (8.2–11.7)	0.9% (0.3–2.2)	5.2% (3.8–7.6)	–
2024 [1]	0.3% (0.2–0.7)	2.6% (1.7–3.8)	–	19.4% (15.4–24.0)	11.2% (9.6–13.2)	0.6% (0.2–1.3)	2.6% (1.9–3.5)	13.4% (9.9–17.7)

[1] *Pelican and cormorant colonies in Upper Klamath Lake were not scanned for PIT tags, resulting in minimum estimates of predation in 2024.*

Appendix B

As part of the SARP, new rearing and release strategies for hatchery reared suckers have been developed in recent years. These include soft release strategies to rear SARP suckers in net pens within Upper Klamath Lake and other water bodies in the UKB, like Gerber Reservoir. The U.S. Geological Survey found that a larger release size of LRS and SNS, supplemental oxygenation systems, and location of net pens can improve survival of SARP fish in Upper Klamath Lake (Caldwell et al. 2023, Banet et al. 2024b). The U.S. Fish and Wildlife Service Net Pen Project began in 2019 and has since released thousands of SARP suckers into net pens with objectives to provide *in situ* rearing locations in predator-free environments, monitor growth and survival before release, and rear captive hatchery stocks at lower densities (USFWS 2025). In the fall, fish are removed from U.S. Fish and Wildlife net pens and released into Upper Klamath Lake. SARP suckers have also been released at other locations, like Lakeside Farms, which is an alternative rearing location that is adjacent, but not connected to Upper Klamath Lake (USFWS 2025). Only a few fish have been recovered from Lakeside Farms and repatriated to Upper Klamath Lake to-date.

Avian predation on SARP suckers reared in net pens and Lower Klamath National Wildlife Refuge ponds and subsequently released into Upper Klamath Lake and SARP suckers reared in Lakeside Farms are investigated herein. Other groups of suckers, such as those released from the Klamath Tribes Fish Hatchery, Chiloquin, OR, and juvenile suckers salvaged in A-Canal Forebay (USFWS 2025), rehabbed at the SARP hatchery, and released in Upper Klamath Lake, may also be of interest to managers concerned with avian predation effects.

Sample sizes of Klamath Tribes Fish Hatchery and SARP juvenile suckers reared and released using alternative strategies were often small (Table B.1), especially compared with those released directly into Upper Klamath Lake. Not all fish released into net pens survived prior to release, and thus, only fish that survived and had release records into Upper Klamath Lake were available for analysis (Table B.1). While there were thousands of SARP tagged suckers released into Lakeside Farms (USFWS 2023b, USFWS 2024, USFWS 2025), not all tagged fish were scanned prior to release. Only tagged fish with known remote detections or physical captures in Lakeside Farms were used in predation analyses (Table B.1).

Table B.1. Numbers of Klamath Tribe Hatchery suckers, juvenile rehabilitated, and juvenile Sucker Assisted Rearing Program (SARP) fish available from U.S. Geological Survey (USGS) and U.S. Fish and Wildlife Service (FWS) net pens and Lower Klamath National Wildlife Refuge ponds and subsequently recovered (in parentheses) on piscivorous waterbird breeding colonies in the Upper Klamath Basin following the 2021–2024 breeding seasons. Recoveries represent the total number of suckers consumed from all scanned bird colonies combined. Tag recoveries only include those tags that were recovered on breeding colonies the same year the fish was determined to be available to avian predators, and the number was not adjusted to account for detection or deposition probabilities and thus represents minimum numbers of consumed tagged fish each year (see Methods). Dashed line (–) denotes that sample sizes of available tagged fish were < 100. Not available (NA) denotes fish groups that were not released that year.

Location [1]	Fish Group	2021	2022	2023	2024 [2]
Upper Klamath Lake	Klamath Tribes Hatchery (juvenile/adult)	1,035 (0)	913 (9)	–	960 (17)
	Salvage Rehabbed (juvenile/adult)	1,636 (3)	–	508 (13)	858 (24)
	Juvenile USGS Net Pen (SARP)	138 (2)	NA	NA	22 (1)
	Juvenile FWS Net Pen (SARP)	–	–	1,848 (44)	1,059 (25)
	Juvenile FWS Lower Klamath Refuge Ponds (SARP)	–	–		385 (26)
Lakeside Farms	Juvenile (SARP)	–	257 [1] (4)	391 [1] (3)	688 (32)

[1] An unknown number of tagged fish were released into Lakeside Farms in 2023. Only known tagged, released, and recovered fish are reported.

[2] Pelican and cormorant colonies in Upper Klamath Lake but were not scanned for tags following the 2024 breeding season.

An investigation of avian predation on other, experimental releases of suckers in the UKB indicated that predation rates were highly variable depending on the group of fish and year, with estimates ranging from < 0.1% to 17.9% (11.7–25.7) during 2021–2024 (Table B.2). Estimates of predation on net pen suckers were substantial, ranging from 6.7% (1.9–17.5) to 9.1% (6.8–12.2), but sample sizes were small (for USGS net pens) or an unknown percentage of fish were potentially dead prior to being consumed by birds (for FWS net pens). For instance, although the net pens had mesh to prevent birds from foraging in them, its possible birds were still able to remove fish, especially dead fish, from the net pens. In addition, dead fish from FWS net pens were disposed of in Upper Klamath Lake and could be foraged on by birds. While most mortalities were scanned for a PIT tag prior to disposal in Upper Klamath Lake, some FWS net pen mortalities were not scanned prior to disposal and may be associated with unknown tag recoveries. A new rearing location of SARP fish, Lower Klamath National Wildlife Refuge ponds, was also used to rear fish prior to release in Upper Klamath Lake. Predation rates on these fish were 17.9% (11.7-25.7%), higher than all releases from net pens. Predation rates on rehabilitated suckers, fish captured from other waterbodies and released in Upper Klamath Lake, were lower in 2024 compared to 2023, and estimates were lower than predation on SARP juveniles that were also released in UKL in 2024 (Table B.2). Estimates of predation on Klamath Tribes suckers were lower than many other experimental releases, <0.1% in 2021 to 4.4% (2.7-6.9) in 2024. Predation on SARP juveniles with known tags released at Lakeside Farms ranged from <0.1% in 2022 to 11.2% (7.7-15.8) in 2024, but here too, results should be interpreted cautiously given small sample sizes and uncertainties regarding release dates and how representative known tagged fish were of all fish released at Lakeside Farms. Interestingly, there were

three Lakeside Farms fish that were also detected on the remote Willow Creek PIT tag arrays in the Clear Lake Basin in 2024. Of these three tags from Lakeside, one PIT tag was recovered on a Clear Lake east lobe avian colony with the suspicion that all three Lakeside Farms SARP fish detected on the Willow Creek PIT tag array were consumed by avian predators and the avian predator swam over the PIT tag array.

Table B.2. Estimated cumulative avian predation rates (95% credible intervals) on PIT-tagged suckers from the Sucker Assisted Rearing Program (SARP) Net Pen and Lower Klamath National Wildlife Refuge (LKNWR), juvenile rehabilitated (Rehabbed), and Klamath Tribes Hatchery at different release locations (Upper Klamath Lake, Lakeside Farms {Lakeside}, and Sheepy Lake) by piscivorous colonial waterbirds nesting at colonies in the Upper Klamath Basin. Some SARP suckers were reared in U.S. Fish and Wildlife Service (FWS) and U.S. Geological Survey (USGS) net pens (Net Pen) prior to release in Upper Klamath Lake. Predation estimates are for SARP fish available in the spring (Spr)/summer (Sum) or fall/winter (Win), where applicable. Predation estimates are adjusted to account for PIT tag detection and deposition probabilities that were unique to each predator species, colony, and year (see Methods). Dashed line (–) denotes that no fish were released at that location, in that year. NA denotes that sample sizes were too small to generate reliable predation rate estimates.

	Upper Klamath Lake							Lakeside	Sheepy Lake
Year	SARP Spr/Sum	SARP Fall/Win	SARP FWS Net Pen	SARP FWS LKNWR	USGS Net Pen	Juvenile Rehabbed	Klamath Tribes	SARP	SARP Spr/Sum
2021	1.8% (1.3–2.3)	2.5% (1.9–3.4)	–	–	6.7% (1.9–17.5)	1.6% (0.5–3.9)	< 0.1%	–	–
2022	4.2% (3.3–5.5)	2.2% (1.4–3.4)	–	–	–	–	4.0% (1.6-8.8)	< 0.1%	–
2023	19.7% (16.6–23.3)	9.8% (8.2–11.7)	9.1% (6.8–12.2)	–	–	12.5% (6.1–23.5)	–	5.9% (2.5–12.5)	59.2% (47.1–78.6)
2024[1]	19.4% (15.7–24.0)	11.2% (9.6–13.2)	5.9% (3.8–8.6)	17.9% (11.7–25.7)	NA	7.1% (4.6–10.5)	4.4% (2.7–6.9)	11.2% (7.7–15.8)	–

[1] *Pelican and cormorant colonies in Upper Klamath Lake were not scanned for PIT tags, resulting in minimum estimates of predation in 2024.*