Predation of Lost River and Shortnose Suckers by Piscivorous Colonial Waterbirds in the Upper Klamath Basin: An Analysis of Predation Effects During 2021–2023

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Final Report: October 17, 2024

ABSTRACT

Previously published research indicated that predation by piscivorous colonial waterbirds in the Upper Klamath Basin was a source of mortality for Lost River suckers (*Deltistes luxatus*) and Shortnose suckers (*Chasmistes brevirostris*), including mortality of Sucker Assisted Rearing Program (SARP) fish. Avian predation on recently released Chinook Salmon (*Oncorhynchus tshawytscha*) in the Upper Klamath Basin has not been studied. To provide fisheries managers with the most up-to-date information, we estimated predation rates on passive integrated transponder tagged (PIT) suckers and Chinook Salmon 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*), and Great Egrets (*A. alba*) during 2021–2023. Predation rate estimates were variable depending on the fish species, age-class (juvenile, adult), waterbody (Upper Klamath Lake, Clear Lake Reservoir, Sheepy Lake), and year. Results indicated that avian predation rates were highest on juvenile suckers and on suckers in Clear Lake Reservoir. SARP fish released in the spring/summer were more likely to be consumed by breeding birds than those released in the fall/winter, although the number of fish released in the fall/winter that survived to the spring/summer was unknown and could bias predation estimates low. Predation rate estimates on Chinook Salmon varied by year, release timing (spring/summer, fall/winter), release location (Upper Klamath Lake, Klamath River), and age-class (subyearling, yearling). The location and size of colonies were also highly variable depending on the bird species, colony location, and year. Future research could focus on identifying biotic and abiotic factors associated with sucker susceptibility to piscivorous colonial waterbirds and determining to what degree avian predation limits the recovery of suckers in the Upper Klamath Basin.

INTRODUCTION

Several species of piscivorous colonial waterbirds nest in the Upper Klamath Basin (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. 2022a). Two species of long-lived catostomids, the Lost River sucker (*Deltistes luxatus)* and the Shortnose sucker (*Chasmistes brevirostris)*, are also native species that are endemic to the UKB and are listed as endangered (U.S. Endangered Species Act, ESA 1973; USFWS 1988). 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 et al. 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). The SARP operates under the hypothesis that poor water quality conditions in Upper Klamath Lake greatly reduces the survival of juvenile suckers. Starting in 2016, wild-origin sucker larvae have been captured and reared at off-site facilities for 1–3

years before being released back into Upper Klamath Lake to bolster survival during the juvenile life stage (Day et al. 2017). Recently published research indicated that predation by colonial waterbirds is among the highest quantified source of sucker mortality across both juvenile and adult life stages (Evans et al. 2022a). Avian predation impacts, however, were variable, depending on the sucker species, life stage (juvenile, adult), waterbody (Upper Klamath Lake, Clear Lake Reservoir, Sheepy Lake, Tule Lake), and year. For instance, Evans et al. (2022a) documented annual predation rates (percentage of available fish consumed by breeding birds) on passive integrated transponder (PIT) tagged suckers that ranged annually from 0.1% (<0.1–0.2, 95% credible interval) to 7.2% (2.8–16.4) on adult suckers and from 4.3% (0.9–13.2) to 10.5% (3.8–24.5) on wild juvenile suckers during 2009–2020. The location and size of piscivorous waterbird breeding colonies were also variable depending on the bird species, colony location, and year.

Chinook Salmon (*Oncorhynchus tshawytscha*) were historically present in the UKB. The construction of Copco 1 Dam on the Klamath River blocked migrations of most 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 south 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 Chinook Salmon beginning in 2022, prior to dam removal. The impact of avian predation on Chinook Salmon released in a novel environment remains unclear with the numerous piscivorous waterbirds present in the UKB.

To ensure that the Bureau of Reclamation, the U.S. Fish and Wildlife Service, ODFW, regional tribes, and other interest groups have the most recent information available regarding avian predation impacts on fish species of interest in the UKB, we have updated the results of Evans et al. (2022a) for ESA-listed suckers and estimated avian predation on non-listed Klamath Largescale sucker (*Catostomus snyderi*) and recently released Chinook Salmon with data collected during 2021–2023. Avian predation estimates are still considered minimum estimates since not all species of piscivorous birds have been studied. An initial pilot study in 2022 on other piscivorous waterbirds, Great Blue Herons and Great Egrets, detected both sucker and Chinook Salmon PIT tags on avian colonies, leading to an expansion of the number of avian species studied beginning in 2023. More specifically, the goals of this study were to identify the location and size of piscivorous waterbird colonies in the UKB and to estimate predation rates on Chinook Salmon and different groups of PIT-tagged suckers, including SARP fish.

METHODS

Herein we provide truncated methods regarding piscivorous colonial waterbird surveys, the availability of PIT-tagged fish (suckers, Chinook Salmon), PIT-tag recovery methods on bird colonies, and the analytical framework used to calculate predation rates. A more detailed description of these methods, including model formulations, is provided in Evans et al. (2022a).

Study area – We investigated predation on PIT-tagged suckers 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 and Great Egrets (collectively hereafter "herons") breeding in and around Upper Klamath Lake, OR, Clear Lake Reservoir, CA, Tule Lake, CA, and Sheepy Lake, CA, during 2021–2023 (Figure 1). Pelicans, cormorants, and terns are all species that were previously identified as posing a potential risk to sucker survival in the region (Evans et al. 2022a). Colonies of herons and gulls, however, had not previously been investigated but were included in this updated analysis due to concerns that these colonies may pose a potential, but unknown, predation risk to suckers and salmon. Pilot studies conducted on heron, egret, and gull nesting areas, specifically in 2022–2023, predicted that these species could consume fish < 300 mm, the release size of most SARP suckers and juvenile Chinook Salmon.

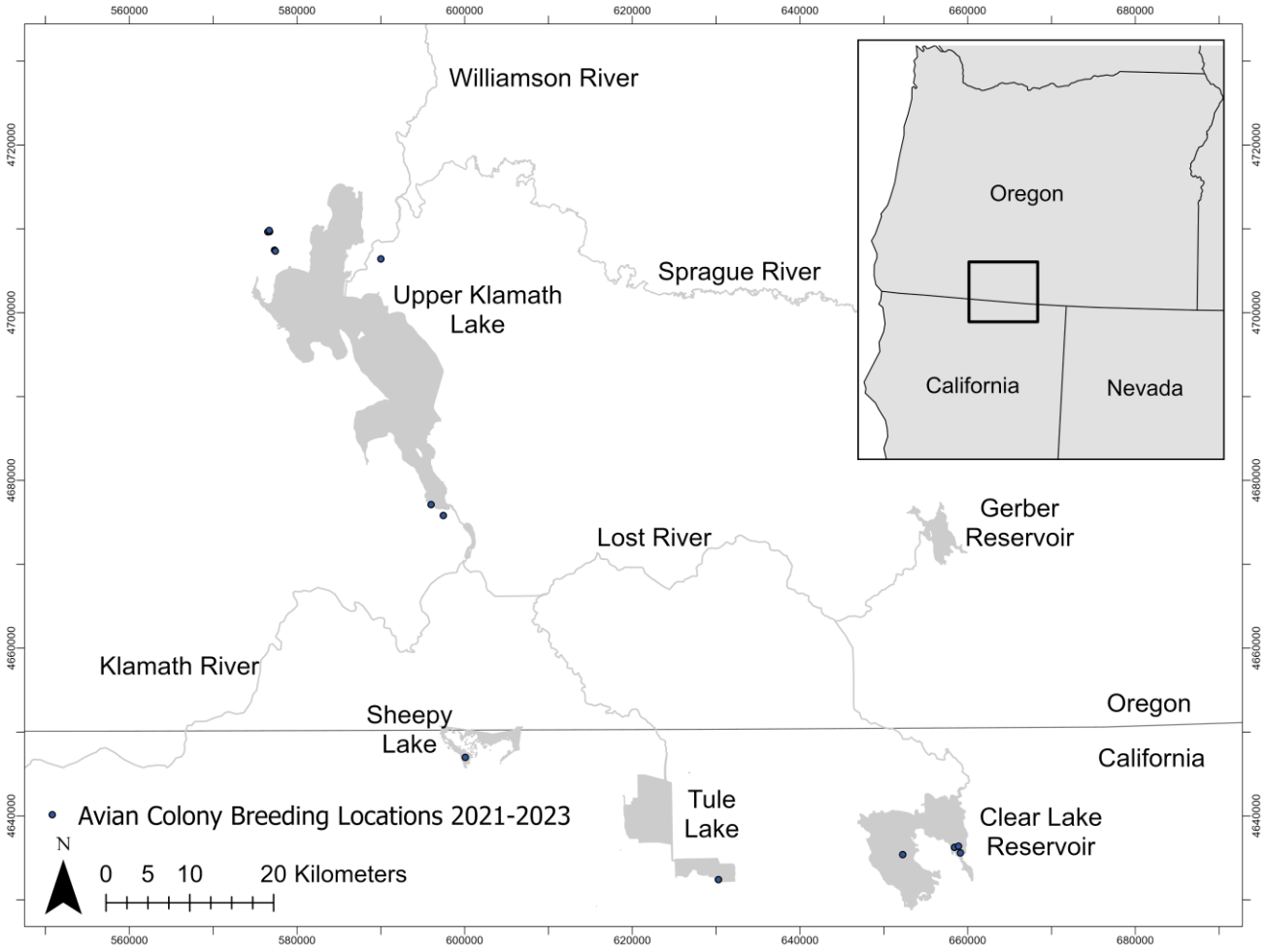

Figure 1: Location of piscivorous waterbird breeding colonies (dots) scanned for passive integrated transponder tags implanted in fish during 2021–2023.

Colony Locations and Sizes – Colony sizes were estimated based on the number of adult birds visible in oblique aerial photographs taken of colonies during the peak breeding period (May to June), with one to three aerial surveys conducted each breeding season (8 June 2021, 30 May 2022, 11 May 2023, 30 May 2023, and 21 June 2023). Aerial surveys and photos for 2021 and 2022 were provided by Oregon State University since colonies in the UKB were part of their regional colonial waterbird survey efforts in those years. Peak colony size was based on the number of adults, and in some cases breeding pairs (in 2021), 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). In 2021 and 2022, counts are reported from the one aerial survey in those years. In 2023, counts were conducted for three aerial surveys with the highest count considered the peak count. Colony size was estimated by digitizing high resolution aerial imagery at each colony and enumerating visible birds by species using ArcGIS (ESRI 2020. ArcGIS Desktop: Release 10.8.1. Redlands, CA). 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 were based on the number of PIT-tagged fish released or re-encountered (previously tagged) between 1 September and 31 August (Evans et al. 2016). 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), 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 2021–2023 and into Sheepy Lake during 2023 were provided by the U.S. Fish and Wildlife Service – Klamath Falls Field Office. Releases of SARP fish occurred during the spring/summer (March to August) or fall/winter (September to February), depending on the year. In addition to PIT-tags, radio telemetry tags and acoustic tags were also inserted into some SARP fish and Chinook Salmon (i.e., fish were double-tagged), 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. (2022a). Release histories of juvenile Chinook Salmon into Upper Klamath Lake and its tributaries also occurred in the spring/summer and fall/winter. Release histories of juvenile Chinook Salmon into the Klamath River occurred in the

spring/summer. Data were provided by ODFW for releases during 2022–2023. Chinook Salmon released in the spring/summer were yearlings (fish greater than 1 year old), while fish released in fall/winter were subyearlings (fish < 1 year old). Finally, although not the primary focus of this study, other groups of experimental suckers (e.g., Klamath Tribes Fish Hatchery, juvenile rehabbed suckers, juvenile suckers released from net pens, and SARP suckers released at Lakeside Farms) were also PIT-tagged and released in the UKB. These experimental groups are reported separately in Appendix B, Table B.1.

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 December). Electronic detections were recorded using hand-held PIT tag antennas and transceivers (Evans et al. 2022a). 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 when possible or as mixed or co-nesting breeding sites (see also Evans et al. 2022a). Scans of non-breeding (loafing, roosting) sites were conducted in 2022 and 2023. Tags detected at loafing/roosting sites were indirectly incorporated in predation rate analyses through estimates of PIT-tag deposition probabilities (see Predation Rates *below*). They also provide information to fisheries managers interested in knowing fates of tagged fish. Other groups of tagged fish (e.g., Klamath Tribes Fish Hatchery, juvenile rehabbed suckers, juvenile suckers released from net pens, and SARP suckers released at Lakeside Farms) with detected PIT-tags are reported in Appendix B, Table B.1.

Predation Rates – A hierarchical Bayesian model was used to estimate predation probabilities or rates (proportion or percentage of available fish consumed by breeding birds) on suckers and Chinook *S*almon based on the number of PIT-tagged fish available and the number of tags recovered on Upper Klamath Lake, Clear Lake Reservoir, Tule Lake, and Sheepy Lake bird colonies each year (Evans et al. 2022a). 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 is consumed (predation probability), (2) the probability that the tag is deposited on the nesting colony (deposition probability), and (3) the probability that the tag is 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 each year to model detection probabilities throughout the breeding season using logistic regression (see Evans et al. 2022 and Appendix A, Table A.1). 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 Hostetter et al. 2015, Evans et al. 2022a, and Appendix A, Table A.2). No previously published PIT tag deposition probability estimate was available for heron colonies. In lieu of empirical data, we used 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 consume large-sized prey items, like adult SNS and LRS. The validity of this assumption, however, is untested, so predation rate estimates by heron colonies should be interpreted cautiously.

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. Results, however, should be interpreted cautiously for groups where < 500 PIT-tagged fish were available (Evans et al. 2012). 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). Detailed predation rate modelling methods, including assumptions and formulations, are provided in Evans et al. (2022a). Predation rates on other groups of tagged fish (Klamath Tribes Fish Hatchery, juvenile rehabbed suckers, juvenile suckers released from net pens, and SARP suckers released at Lakeside Farms) are reported in Appendix B, Table B.2.

RESULTS AND DISCUSSION

Bird Colony Locations and Sizes – Colonial waterbirds often arrive to nest in the UKB in late February and March and remained on-colony until August (Evans et al. 2016). During 2021–2022, colony monitoring was limited to a single survey, so results have higher uncertainty in terms of the peak number of breeding individuals or pairs in those years. Results of colony surveys indicated that the number of pelicans (individual adults) counted on all breeding sites in UKB ranged annually from 646 in 2022 to 2,092 in 2023 (Table 1). The total number of cormorants at all breeding sites ranged annually from 856 in 2021 to 1,213 in 2023 (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 Sheepy Lake and Clear Lake Reservoir with colony sizes ranging annually from 290 individuals in 2023 to 476 breeding pairs in 2021. Herons were only counted in 2023 with 574 individuals that occupied three tree-nesting colony locations around Upper Klamath Lake (Table 1), typically nesting in the canopy of Ponderosa Pines (*Pinus ponderosa*). Only herons occupied these tree-nesting colonies, providing the opportunity to examine heron-specific avian predation impacts on fish. Smaller heron colonies, primarily ground-nesting, are also observed at Clear Lake, although adjacent to other nesting waterbird species (Table 1). While gull colonies were not counted as part of this study, gull colonies in the UKB are typically over 1,000 individuals (Shuford 2010). Some gull nesting areas at mixed-species colonies like Sheepy Lake were delineated to explore predation rates by these colonial waterbirds. Although gulls are not strictly piscivorous and are limited by prey size, further study is needed on the size of gull colonies and whether predation impacts on juvenile Chinook *S*almon and suckers are similar to other colonial waterbirds (see also Predation Rates *below*).

Avian species composition varied by nesting site and year, with mixed-species nesting sites observed at Upper Klamath Lake (cormorants, pelicans), Clear Lake (cormorants, gulls, herons, pelicans, and terns), Sheepy Lake (cormorants, gulls, pelicans, and terns), and Tule Lake (cormorants, gulls, and pelicans; Table 1). Certain mixed-species sites had areas where researchers could scan species-specific nesting

areas such as tern colonies at Sheepy Lake and Clear Lake. Although Tule Lake had two islands available to piscivorous waterbirds in 2021, only one was occupied by cormorants, pelicans, and gulls based on one aerial survey. In 2022 and 2023, all historical breeding colonies in Tule Lake were land bridged as there was no water in Tule Lake Sump 1B. The absence of birds at Upper Klamath Lake colonies during the one aerial survey in 2021 might also be related to low water levels. Lack of secure nesting habitat at some locations, like Tule Lake and Upper Klamath Lake, in drought years like 2021 may cause birds to nest outside of the UKB. Alternatively, birds may congregate at a smaller number of secure nesting sites within the basin, not breed and remain in the UKB if prey availability was favorable, or initiate breeding at a site with the risk of that site being land-bridged as water levels recede, thus risking mammalian predation.

Multiple aerial surveys conducted over the course of one breeding season, like 2023, provided the most accurate colony counts and delineations of areas to scan for PIT-tags. New developments occurred on each aerial survey in 2023. A pelican colony that was present in Upper Klamath Lake on the second survey was absent from the other two surveys. A tern colony present on the second and third surveys was absent on the first survey. In contrast, single aerial surveys in 2021 and 2022 provided limited information in nesting chronology, when and if colonies failed or successfully fledged young, and how the colony area changed over the course of the breeding season. Cormorant and pelican nesting sites in Upper Klamath Lake failed at some point during the 2021 breeding season prior to the June 6, 2021, aerial survey. Since no birds were present at the time of the June survey, counts of colony size were not available (Table 1) and delineating exact colony areas to scan for PIT tags was a best guess based on what appeared to be failed nesting sites. Multiple aerial surveys are recommended in future years as a cost-effective method to identify colony locations that can be dynamic with variable water conditions in high desert ecosystems.

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 and Great Egrets (herons) by nesting location (Upper Klamath Lake, Clear Lake Reservoir, Sheepy Lake, and Tule Lake) and year. 'NA' denotes a colony may have been active, but counts were not available. 'Active' denotes a colony that was active but not counted.

Nesting Location	Species	2021	2022	2023
Upper Klamath Lake [1]	Pelicans	NA[3]	97	232
	Cormorants	NA[3]	158 [4]	370
	Herons	NA	Active	574
Clear Lake Reservoir [2]	Pelicans	1,094 [4]	509	1,621
	Cormorants	110 [5]	114 [4]	163
	Terns	152 [5]	0	202
	Herons	Active	NA	15
	Gulls	Active	Active	Active
Sheepy Lake	Pelicans	169 [4]	40	239
	Cormorants	420 [5]	723 [4]	680
	Terns	324 [5]	277 [4]	290
	Gulls	Active	Active	Active
Tule Lake	Pelicans	338 [4]	0	0
	Cormorants	326 [4]	0	0
	Terns	0	0	0
	Gulls	NA	0	0

[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.

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, waterbody (Upper Klamath Lake, Clear Lake Reservoir), and year. Large sample sizes of available PIT-tagged adult LRS were available in Upper Klamath Lake, ranging annually 11,934 to 15,880 tagged fish (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 substantially smaller, ranging annually from 668 to 1,444 PIT-tagged fish (Table 2, Hewitt et al. 2021). Sample sizes of SNS in Upper Klamath Lake and SNS/KLS in Clear Lake Reservoir ranged annually from 3,639 to 3,766 and 1,553 to 5,484 PIT-tagged fish, respectively (Table 2). Although KLS are not targeted specifically in sampling efforts of LRS and SNS, thousands of KLS have been PIT-tagged in previous years. Sample sizes of adult KLS in Upper Klamath Lake ranged annually from 587 to 842 PIT-tagged fish (Table 2).

Numbers of PIT-tagged SARP juveniles released into Upper Klamath Lake and its tributaries ranged annually from 3,571 to 8,445 during the spring/summer and 4,166 to 8,605 during the fall/winter periods during 2021–2023 (Table 2). Fish released during the fall/winter period were susceptible to predation by non-breeding piscivorous waterbirds during fall/winter (not quantified in this study) and breeding piscivorous waterbirds on colonies included in this study during spring/summer. It is not clear how predation by non-breeding birds in fall/winter may affect availability numbers of fall/winter SARP juveniles. SARP fish released in the spring/summer period were presumably susceptible to predation by mostly breeding piscivorous waterbirds on the colonies included in the study immediately following release. A total of 974 PIT-tagged SARP fish were released into Sheepy Lake during the spring/summer of 2023 (Table 2). This was the first known release of SARP fish in a water body outside of designated critical habitat units in Upper Klamath Lake and the Lost River Basin for LRS and SNS. Only small numbers of PIT-tagged wild juveniles were available for use in predation analyses, with 100 or more PIT-tagged wild juveniles available in Upper Klamath Lake in 2022 (n=187) and in Clear Lake Reservoir in 2022 (n=113; Table 2). 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 six of the last 15 years (Table 2 and Appendix A, Table A.3). Despite extensive efforts to sample wild juveniles, low catch rates of wild juveniles of taggable size in Upper Klamath Lake 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. This also contributes to lower sample sizes for wild juvenile suckers in Upper Klamath Lake and Clear Lake. While there was a total of 120 detections or captures of SARP suckers > 300 mm, availability numbers were < 100 in each year of the study, and these fish were included in analysis of SARP juveniles. Future years with larger availability numbers for surviving SARP fish > 300 mm can potentially be used to investigate predation on larger SARP fish and if some predators are limited by SARP prey size, such as terns or gulls. Numbers of available PIT-tagged adult and juvenile suckers used in predation analyses during 2009–2020, those presented in Evans et al. (2022a), are reported in Appendix A, Table A.3.

Numbers of PIT-tagged hatchery juvenile Chinook Salmon released into Upper Klamath Lake and its tributaries ranged annually from 6,567 to 7,773 during the spring/summer of 2022–2023 (Table 2). A total of 423 PIT-tagged Chinook Salmon were released into Upper Klamath Lake during the fall/winter of 2022–2023. Chinook Salmon released into the Klamath River ranged annually from 432 to 759 during the spring/summer of 2022–2023 (Table 2).

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 (in parentheses) on piscivorous waterbird colonies in the Upper Klamath Basin during the 2021–2023 breeding seasons. Releases of juvenile SARP suckers and Chinook Salmon occurred during the spring/summer (Spr/Sum) or fall/winter (Fall/Win). Recoveries represent the total number of suckers consumed from all bird colonies combined (see Appendix A, Table A.3 for recoveries by nesting location). 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). NR denotes fish that were not released in that water body and year.

Location [1]	Fish Group [2]	2021	2022	2023
Upper Klamath Lake	Adult LRS	15,880 (15)	13,781 (0)	11,934 (30)
	Adult SNS	3,766 (6)	3,706 (0)	3,639 (31)
	Adult KLS	587 (3)	793 (0)	842 (2)
	Juvenile suckers (Wild)	41 (0)	187 (0)	45 (1)
	Juvenile suckers (SARP–Spr/Sum)	8,112 (59)	8,445 (118)	3,571 (226)
	Juvenile suckers (SARP–Fall/Win)	8,605 (79)	4,166 (26)	7,908 (224)
	Juvenile Chinook Salmon (Spr/Sum)	NR	6,567 (77)	7,773 (455)
	Juvenile Chinook Salmon(Fall/Win)	NR	NR	423 (2)
Klamath River	Juvenile Chinook Salmon (Spr/Sum)	NR	432 (13)	759 (83)
Clear Lake Reservoir	Adult LRS	668 (42)	1,403 (2)	1,444 (3)
	Adult SNS-KLS	1,553 (35)	2,954 (8)	5,484 (105)
	Juvenile sucker (Wild)	74 (3)	113 (2)	60 (1)
Sheepy Lake	Juvenile (SARP–Spr/Sum)	NR	NR	974 (169)

[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, released by The Klamath Tribes, or double-tagged (PIT, radio/acoustic) were excluded; see Appendix B.

PIT Tag Recovery – For adult suckers, PIT tags from 5 KLS, 45 LRS and 37 SNS from Upper Klamath Lake and 47 LRS and 148 SNS/KLS from Clear Lake Reservoir were recovered on bird colonies following the 2021–2023 breeding seasons (Table 2). No PIT tags from available adult or juvenile suckers were recovered from bird colonies on Tule Lake in 2021, the only year during the present study that piscivorous waterbirds were observed and the colony was scanned. For wild juvenile suckers in 2022, the only year more than 100 wild fish were available for predation analyses, no (zero) PIT tags from Upper Klamath Lake suckers and 2 PIT tags from Clear Lake suckers were recovered following the 2022 breeding seasons (Table 2). For SARP suckers released in Upper Klamath Lake, 732 PIT tags were

recovered following the 2021–2023 breeding seasons. For SARP suckers released in Sheepy Lake, a new release site for SARP fish in 2023, 169 PIT tags were recovered on bird colonies following the 2023 breeding season (Table 2). Of the Sheepy Lake SARP tags recovered, 156 were recovered on the primary breeding site for piscivorous waterbirds at Sheepy Lake in 2023. A total of 534 PIT tags and 96 PIT tags from juvenile Chinook Salmon released in Upper Klamath Lake and the Klamath River, respectively, were recovered on colonies following the 2022–2023 breeding seasons (Table 2). Appendix A, Table A.4 provides information on the number of tags recovered on bird colonies and avian loafing/roosting sites within each waterbody (Upper Klamath Lake, Clear Lake Reservoir, and Sheepy Lake), regardless of the year the tag was consumed and deposited by a bird (see also Evans et al. 2022a).

Similar to Evans et al. (2022a), the number of tags recovered on bird colonies following each breeding season varied considerably by fish species, age-class, and year. Even within the same sucker species and age-class, the number of tags recovered on bird colonies varied considerably by year. For example, when considering Upper Klamath Lake adult SNS suckers, as few as 0 (zero) tags (in 2022) to more than 30 tags (in 2023) were recovered on bird colonies following each breeding season (Table 2). Unlike recoveries of adult sucker PIT-tags in some years, large numbers of SARP juvenile PIT tags were recovered on bird colonies in the UKB each year, with tags recovered from birds nesting in most waterbodies each year (Upper Klamath Lake, Clear Lake Reservoir, and Sheepy Lake; Table 2 and Appendix A, Table A.4).

A total of 349 newly detected PIT tags were recovered at loafing sites during 2021–2023, which accounts for 75% of all newly detected tags recovered from loafing sites since 2009 (Evans et al. 2022a). 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. Several loafing sites in Agency Lake, where large numbers of piscivorous waterbirds were observed in aerial surveys in 2023, were especially important tag recovery locations resulting in over 200 newly recovered tags. While tags recovered at loafing sites were not directly 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, within the breeding season of piscivorous birds, could lead to a better understanding of avian predation and sucker mortality across space and time.

There was a total of 166 PIT tags recovered on avian colonies of unknown origin during the study period (22 in 2021, 10 in 2022, and 134 in 2023). A number of these tags are expected to be from SARP fish released in the UKB in Lakeside Farms in 2023. The remaining unknown tags may 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 2023 were higher than in previous years. This may be due to scanning new areas (more effort) and associated with differences in release strategies of fish in Upper Klamath Lake and nearby water bodies.

Predation Rates – Estimated cumulative predation rates (predation by all colonies combined) on adult LRS, KLS, and SNS suckers from Upper Klamath Lake were low in most years, ranging annually from < 0.1% to 0.8% (0.5–1.3), < 0.1% to 1.2% (0.3–3.1), and < 0.1% to 2.6% (1.8–3.9), respectively, during 2021–2023 (Table 3). Estimated cumulative predation rates on adult LRS and SNS/KLS from Clear Lake Reservoir, however, were consistently higher than those of suckers in Upper Klamath Lake, ranging annually from 0.5% (0.1–1.5) to 16.1% (11.6–22.4) and 0.9% (0.4–1.9) to 5.5% (3.8–7.9), respectively, during 2021–2023 (Table 3). Estimates of predation on adult LRS suckers from Clear Lake Reservoir in 2021 were the highest observed (ca. 16.1%) on a group of adult suckers since predation studies in the UKB commenced in 2009 (Table 3 and Appendix A, Table A.5). Estimates of predation on both LRS and SNS-KLS suckers from Clear Lake Reservoir were also higher than those observed in adult suckers from Upper Klamath Lake in most years dating back to 2009 (Table 3 and Appendix A, Table A.5). The exact reason for consistently higher predation impacts on adult suckers from Clear Lake Reservoir is unknown. Higher predation risks in Clear Lake may be attributed to lake surface elevation being more affected by drought and water management which affects spawning success and survival of suckers (Hewitt et al. 2021). Avian predation has also been documented in smaller spawning tributaries to Clear Lake with dynamic flows and water control structures (Banet et al. 2021). In the case of predation on adult LRS and SNS from Upper Klamath Lake, annual estimates of predation during 2021–2023 were similar to those observed during 2009–2020, with annual estimates often < 2% of available fish and no more than 3.7% of available fish (Appendix A, Table A.5).

Tags from wild juvenile suckers from both Upper Klamath Lake and Clear Lake Reservoir were recovered on bird colonies in 2021, 2022, and 2023, but samples sizes of available fish were too small (< 100 tagged fish) to generate reliable estimates of predation in most years. Even in cases where more than 100 fish were available, like in Clear Lake Reservoir in 2022 (Table 2), unreliable estimates of predation can occur when sample sizes are < 500 tagged fish (Evans et al. 2012). With this caveat in mind, similar to the results of Evans et al. (2022a), there was evidence 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, an estimated 9.8% (2.8–25.4) of wild juvenile suckers in Clear Lake Reservoir were consumed by birds during the 2022 breeding season compared with predation estimates of < 1.0% on adult LRS and SNS-KLS in Clear Lake Reservoir in 2022 (Table 3). Evans et at. (2022a) theorized that due to their small size (< 300 mm), juvenile suckers are susceptible to predation by multiple bird species (terns, gulls, herons, cormorants, pelicans, and possibly other species) but that adult suckers exceed the gape width of terns and gulls. Cormorants have been documented to consume fish up to ~ 450 mm (Hostetter et al. 2023), so some, but not all, adult-sized suckers are susceptible to cormorant predation. In the present study, 4 tags from fish that were classified as adult suckers were recovered on heron-specific colonies, with the largest being 365 mm LRS in Upper Klamath Lake, so most, but not all, adult suckers may be too large for herons to consume. However, 2023 was the only year all heron colonies in the UKB were analyzed for predation rates. Conversely, all but the largest adult LRS are susceptible to pelican predation, previously known to being LRS > 730 mm (Evans et al. 2016). A PIT tag from an LRS, measured at 746 mm, was recovered at a mixed avian species loafing site in Pelican Bay in 2023.

Table 3. Estimates of predation rates (95% credible intervals) on PIT-tagged Lost River suckers (LRS), Shortnose suckers (SNS), Klamath Largescale suckers (KLS), Shortnose/Klamath Largescale suckers (SNS-KLS), and wild juvenile suckers by piscivorous colonial waterbirds nesting at colonies in Upper Klamath Lake and Clear Lake Reservoir (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. Dashed line (–) denotes that sample sizes of available tagged fish were fewer than 100 so predation rates were not generated (see Methods).

	Upper Klamath Lake Suckers				Clear Lake Reservoir Suckers		
Year	Adult LRS	Adult SNS	Adult KLS	Wild Juveniles	Adult LRS	Adult SNS-KLS	Wild Juveniles
2021	0.3% (0.2–0.6)	0.6% (0.3–1.1)	1.2% (0.3–3.1)	–	16.1% (11.6–22.4)	5.5% (3.8–7.9)	–
2022	< 0.1%	< 0.1%	< 0.1%	< 0.1%	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)	0.9% (0.1–2.4)	–	0.9% (0.3–2.2)	5.2% (3.8–7.6)	–

An investigation of predator- and colony-specific predation rates indicated that predation on adult LRS and SNS-KLS suckers from Clear Lake Reservoir was exclusively from birds nesting on islands in Clear Lake Reservoir (Figure 2). 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, 2022a) 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 were relatively low (< 1%) in most years. In 2023, however, an estimated 2.6% (1.8-3.9) of adult SNS suckers from Upper Klamath Lake were consumed by breeding birds, and most of the predation was from pelicans and cormorants nesting on islands in Upper Klamath Lake, followed by pelicans and cormorants breeding on islands in Clear Lake Reservoir (Figure 2). Predation rates by herons on adult suckers was low in 2023, the only year predation rates on heron-specific colonies were available, ranging from < 0.1% to 0.3% (0.1–1.2) on adult SNS-KLS in Clear Lake on a mixed nesting heron and gull site in 2023, the highest observed on a heron colony (Figure 2). However, the small heron nesting colonies at Clear Lake were adjacent to cormorants and pelicans at Clear Lake and could have been deposited by other waterbirds. While there appeared to be limited predation on adult Clear Lake suckers from terns and Upper Klamath Lake SNS by gulls (Figure 2), terns and gulls are limited to prey that are < 300 mm in size. Thus, adult sucker tags detected at tern and gull nesting areas were likely deposited by cormorants and pelicans. As chicks of all species become more mobile, traveling through other nesting areas becomes more common as the breeding season continues. The majority of tags deposited on species-specific areas were assumed to be of that nesting species.

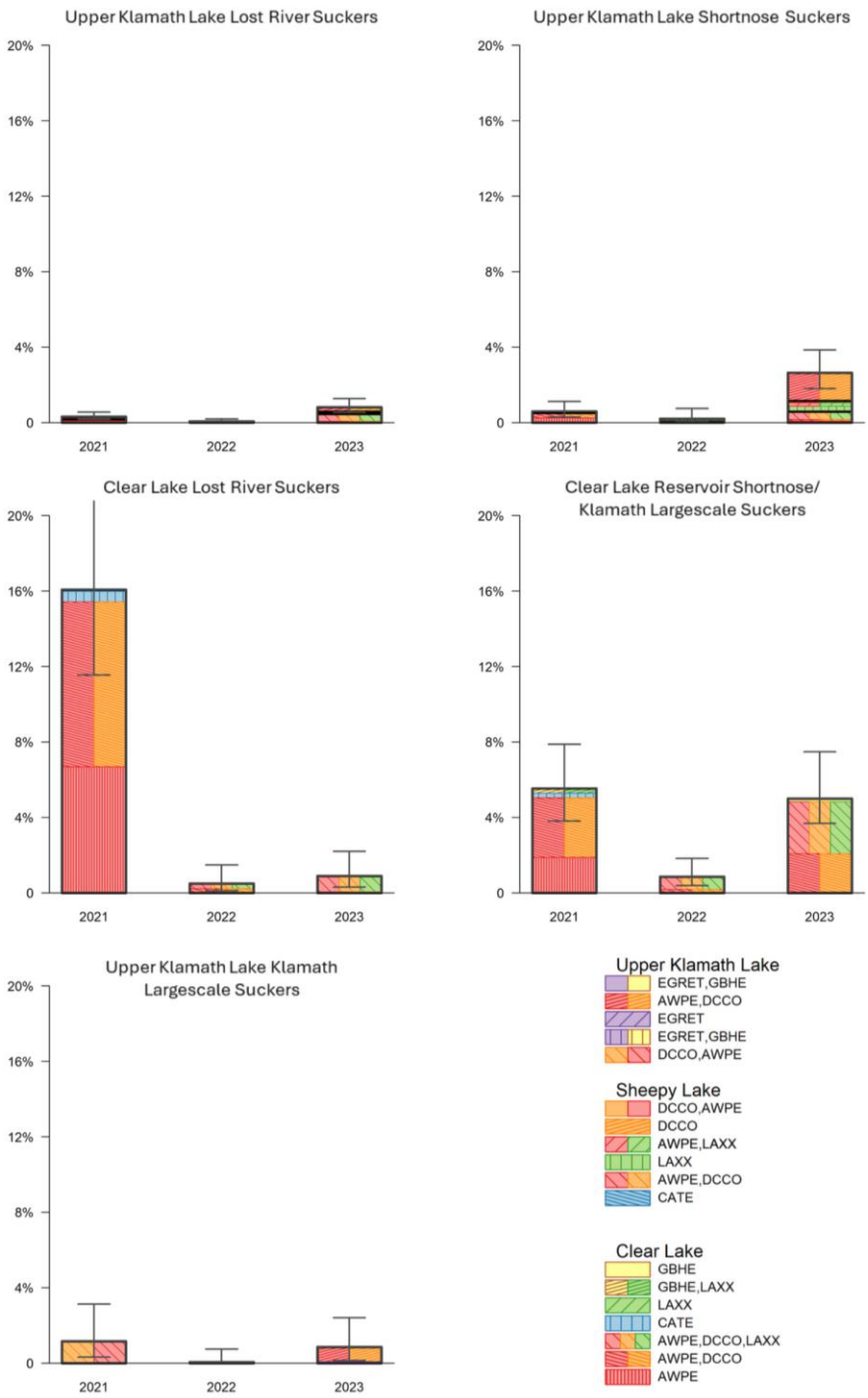

Figure 2. Estimated colony specific- and cumulative predation rates on PIT-tagged adult suckers in the Upper Klamath Basin during 2021–2023. Avian predation species include American White Pelicans (AWPE; red-colored bars), Double-crested Cormorants (DCCO; orange-colored bars), Caspian Terns (CATE; blue-colored bars), California Gulls and Ring-billed Gulls (LAXX; green-colored bars), Great Blue Herons (GBHE; yellow-colored bars) and Great Egrets (EGRET; purple-colored bars). Mixed species colony sites are combination of species. Most colonies were located on islands in National Wildlife Refuges of Upper Klamath Lake, Clear Lake Reservoir, and on Sheepy Lake in Lower Klamath with larger heron rookeries located on the mainland. Error bars represent 95% credible intervals.

Estimated cumulative predation rates on SARP juvenile suckers from Upper Klamath Lake that were released in the fall/winter ranged annually from 2.2% (1.4–3.4) to 9.8% (8.2–11.7) during 2021–2023 (Table 4). Estimated cumulative predation on SARP juvenile suckers released in the spring/summer ranged annually from 1.8% (1.3–2.3) to 19.7% (16.6–23.3) during 2021–2023 (Table 4). The spring/summer SARP release in 2023 was the highest predation rate on SARP fish to date. While 2022 and 2023 suggested that predation of spring/summer SARP releases were approximately double that of fall/winter SARP releases, results should be viewed cautiously. Previous studies of avian predation on SARP suckers analyzed all SARP releases as one availability group (Evans et al. 2022a). This was the first study that examined predation on different SARP release periods as this information could be valuable to fisheries managers interested in minimizing avian predation effects. There may be concerns, however, with assuming all fall/winter SARP fish were available to breeding birds. Following release, an unknown number of fall/winter SARP fish may be susceptible to predation by non-breeding piscivorous waterbirds that are present in the UKB in the fall and winter. Thus, availability of fall/winter SARP suckers may be lower than the number released, which would bias predation rate estimates low. As such, additional years of study may be warranted to investigate predation of SARP releases and comparing release timing.

Estimates of cumulative predation on SARP juveniles released in Sheepy Lake in the spring/summer of 2023 were the highest observed of any sucker species or age-class in the UKB to-date (2009–2023), with an estimated 59.2% (47.2–78.2) of available fish consumed by colonial waterbirds (Table 4). Unlike wild juvenile suckers, samples sizes of SARP juveniles included thousands of tagged fish in all study years, resulting in more precise estimates of predation. Predation estimates in SARP juveniles indicate avian predation is one of the highest known causes of mortality. While there are many unknowns related to juvenile SARP survival following release, SARP suckers have not been documented returning to spawning grounds in numbers that can augment existing spawning populations. Thus, strategies that minimize avian predation, like releasing larger-sized SARP fish to reduce or eliminate predation by some avian species (terns and gulls), may be paramount to increasing survival in the coming years.

Estimated cumulative predation rates on juvenile Chinook Salmon released into Upper Klamath Lake in spring/summer ranged annually from 3.3% (2.2–5.0) to 21.6% (18.0–27.3) in 2022 and 2023, respectively (Table 4). Estimates of predation on juvenile Chinook Salmon released in the fall/winter (5.6% [2.2–13.0]) were lower than those released in spring/summer (21.6% [18.0–27.3]) when comparisons are made during the same breeding season (2023; Table 4). Interestingly, predation by spring/summer Chinook Salmon released in the Klamath River (39.5% [30.4–52.4) were approximately two to three times higher compared to spring/summer Chinook Salmon released in Upper Klamath Lake in the same year (Table 4). Given that juvenile Chinook Salmon releases in the UKB only began in 2022, limited data are available for comparisons of avian predation across years and different release times. Uncertainty remains on the behavior and survival of fish released in fall/winter versus spring/summer and the presumed movement of Chinook Salmon from Upper Klamath Lake to the Klamath River and within the Klamath River. Results suggest high predation rates within 50 km of most release locations in the UKB

that warrant further study. Furthermore, very little is known about avian predation on juvenile Chinook Salmon at other colony locations downstream of the study area, although juvenile Chinook Salmon tags were recovered at off-river cormorant and heron colonies in Lake Shastina, CA in 2023 (Krause et al. 2024).

Table 4. Estimates of predation rates (95% credible intervals) on PIT-tagged Sucker Assisted Rearing Program (SARP) juvenile suckers and juvenile Chinook Salmon (Chinook) by piscivorous colonial waterbirds nesting at colonies in Upper Klamath Lake, Clear Lake Reservoir, and Sheepy Lake combined (i.e., cumulative predation effects). Predation estimates are for SARP fish released in the spring (Spr)/summer (Sum) or fall/winter (Win; see Methods). 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 that year, at that location.

Year	Upper Klamath Lake				Klamath River	Sheepy Lake
	SARP Spr/Sum	SARP Fall/Win	Chinook Spr/Sum	Chinook Fall/Win	Chinook Spr/Sum	SARP Spr/Sum
2021	1.8% (1.3–2.3)	2.5% (1.9–3.4)	–	–	–	–
2022	4.2% (3.3–5.5)	2.2% (1.4–3.4)	3.3% (2.2–5.0)	–	11.0% (6.2–18.8)	–
2023	19.7% (16.6–23.3)	9.8% (8.2–11.7)	21.6% (18.0–27.3)	5.6% (2.2–13.0)	39.5% (30.4–52.4)	59.2% (47.2–78.2)

An investigation of predator- and colony-specific predation rates indicated that SARP juveniles released in Upper Klamath Lake, particularly those released in the spring/summer, were consumed by birds nesting on islands in Upper Klamath Lake, Clear Lake, and Sheepy Lake and that all predator species (pelicans, cormorants, terns, gulls, and herons) consumed them to varying degrees (Figure 3). Additional effort dedicated to investigating other avian mortality sources in 2023, like herons and gulls, resulted in novel findings. For instance, predation rates on SARP juveniles released in Upper Klamath Lake in the spring of 2023 was predominantly from herons nesting in Upper Klamath Lake, followed by cormorants and gulls on Sheepy Lake, and cormorants and pelicans on Upper Klamath Lake (Figure 3). Continued and expanded effort for herons and gulls is planned in 2024. Avian predators included in this study have not been limited by the size of most SARP fish released to-date. Little is known about juvenile sucker habitat use and where mortality is occurring. Given that approximately half of all avian-attributed mortality on Upper Klamath Lake SARP juvenile suckers was from herons in 2023, results suggest that juvenile suckers may be utilizing shoreline and marsh habitats since herons are almost exclusively wading predators. However, herons only had predation rates in 2023, and predation by herons could also be a result of where SARP fish are released, such as shoreline habitat and rivers where herons forage. An investigation of predator and colony-specific predation rates on SARP juvenile releases directly into Sheepy Lake, the highest predation rate observed on any group of fish in the UKB to-date, indicated that majority of losses were due to cormorants, pelicans, and gulls nesting on one island in

Sheepy Lake (Figure 3). Although Lower Klamath Lake once provided habitat for LRS and SNS, much of that habitat is now fragmented wetlands, including Sheepy Lake. In addition, suckers on Sheepy Lake (a part of Unit 2 on the Lower Klamath National Wildlife Refuge) experienced a drastic reduction in available habitat during 2023. Prior to water being added in spring 2024, unit 2 experienced a 95% reduction in flooded area with the remainder of flooded habitat in toe drains and to a smaller degree the remnant of Sheepy Lake (John Vradenburg, USFWS Supervisory Biologist-Klamath Basin National Wildlife Refuge Complex, written communication on October 3, 2024). The habitat constriction in terms of depth and surface area may have led to the high predation rates by making suckers more susceptible to avian predation. Reasons SARP fish were released into Sheepy Lake in 2023 include the need to gauge the quality of that habitat by assessing survival of released fish therein (Megan Skinner, USFWS Water Quality Specialist-Klamath Falls Fish and Wildlife Office, written communication on October 15, 2024) and the lack of capacity to hold SARP fish during construction of the Klamath Falls National Fish Hatchery. Over 3,000 untagged SARP suckers ≤ 95mm total length and more than 13,000 larval suckers were also released in Sheepy Lake in 2023 (USFWS 2024, Joshua Gondek, USFWS Fish Biologist-Sucker Assisted Rearing Program, written communication on August 13, 2024), although predation estimates could only be quantified on the 974 PIT-tagged SARP suckers released during the same time period. Less is known about other release locations of SARP juveniles in other wetlands and closed systems like Lakeside Farms (see Appendix B) given uncertainties in number of tagged fish released at that location.

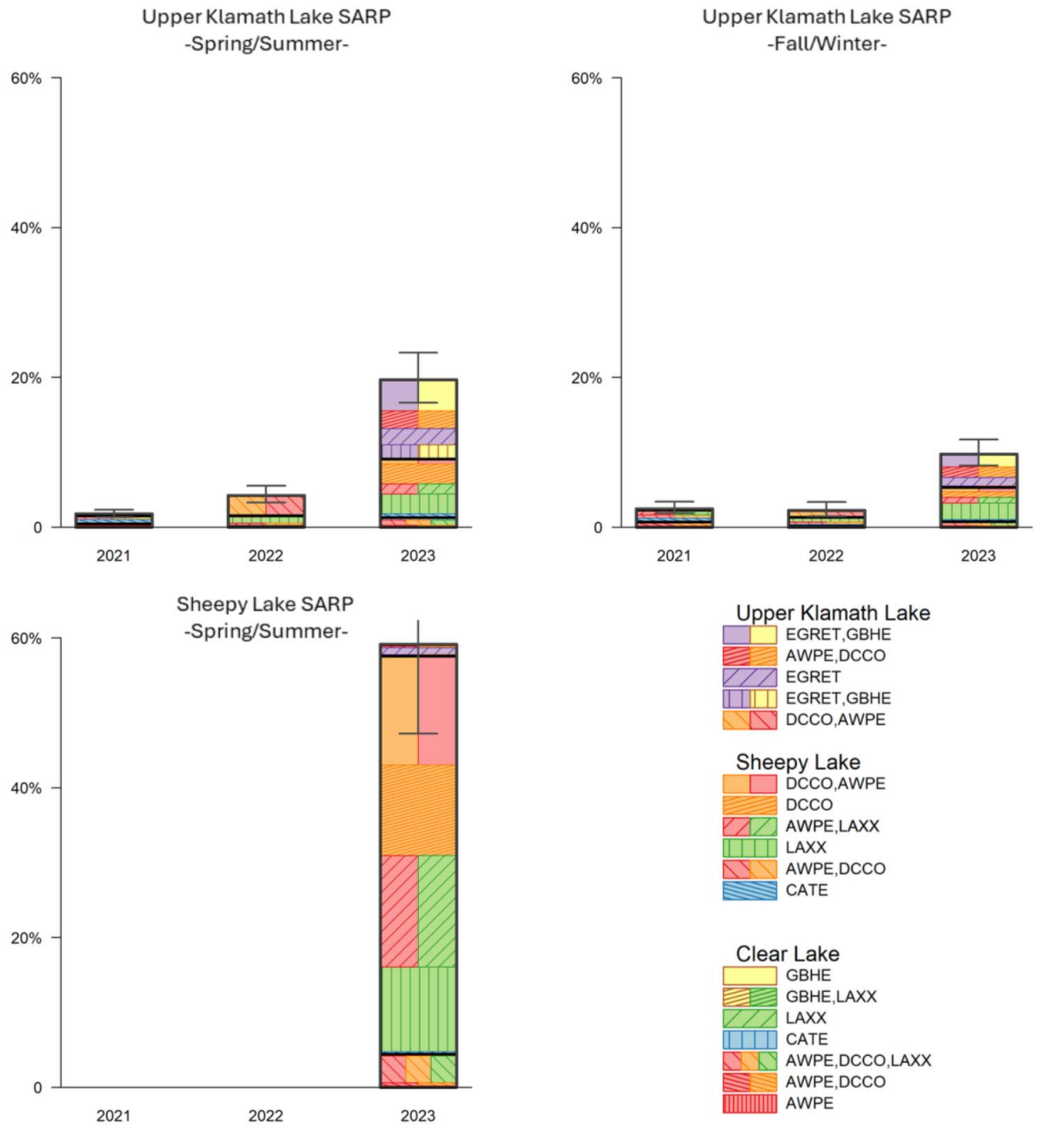

Figure 3. Estimated colony specific and cumulative avian predation rates on PIT-tagged Sucker Assisted Rearing Program (SARP) juvenile suckers released in Upper Klamath Lake and Sheepy Lake during the spring/summer and fall/winter 2021–2023. Avian species include American White Pelicans (AWPE; red-colored 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) and Great Egrets (EGRET; purple-colored bars). Mixed species colony sites are combination of species. Most colonies were located on islands in National Wildlife Refuges of Upper Klamath Lake, Clear Lake Reservoir, and on Sheepy Lake in Lower Klamath with larger heron rookeries located on the mainland. Error bars represent 95% credible intervals.

An investigation of predator- and colony-specific predation rates on juvenile Chinook Salmon indicated that the highest predation rates were from cormorants, pelicans, and gulls nesting on Sheepy Lake, followed by predation from cormorants and pelicans nesting in Upper Klamath Lake and Clear Lake Reservoir (Figure 4). Predation on juvenile Chinook Salmon released in spring/summer of 2023 in Upper Klamath Lake and Klamath River by cormorants, pelicans, and gulls nesting on Sheepy Lake in 2023 was amongst the highest evaluated during the study period. 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 released in Upper Klamath Lake during the spring/summer of 2023. Expanded effort scanning gull colonies in 2023 found that predation by gulls accounted for approximately half of all avian predation on Chinook Salmon released at all time periods and locations. This was a novel finding for the UKB, although gulls are known to consume Chinook Salmon in other basins, like the Columbia River (Evans et al. 2022b). 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 is needed to better understand these and other factors that influence fish susceptibility to avian predation in the UKB (see also *below*). Having another group of available, PIT-tagged fish in the UKB, like Chinook Salmon, may not result in lower predation on suckers. Rather, predation rates on both groups may be similar when comparing the same year, lower predation in 2022 and higher predation in 2023. While further study is needed when reintroduction efforts of juvenile Chinook Salmon are fully underway, results from 2022–2023 suggest high predation rates on Chinook Salmon in the UKB before Chinook Salmon arrive at Keno Dam.

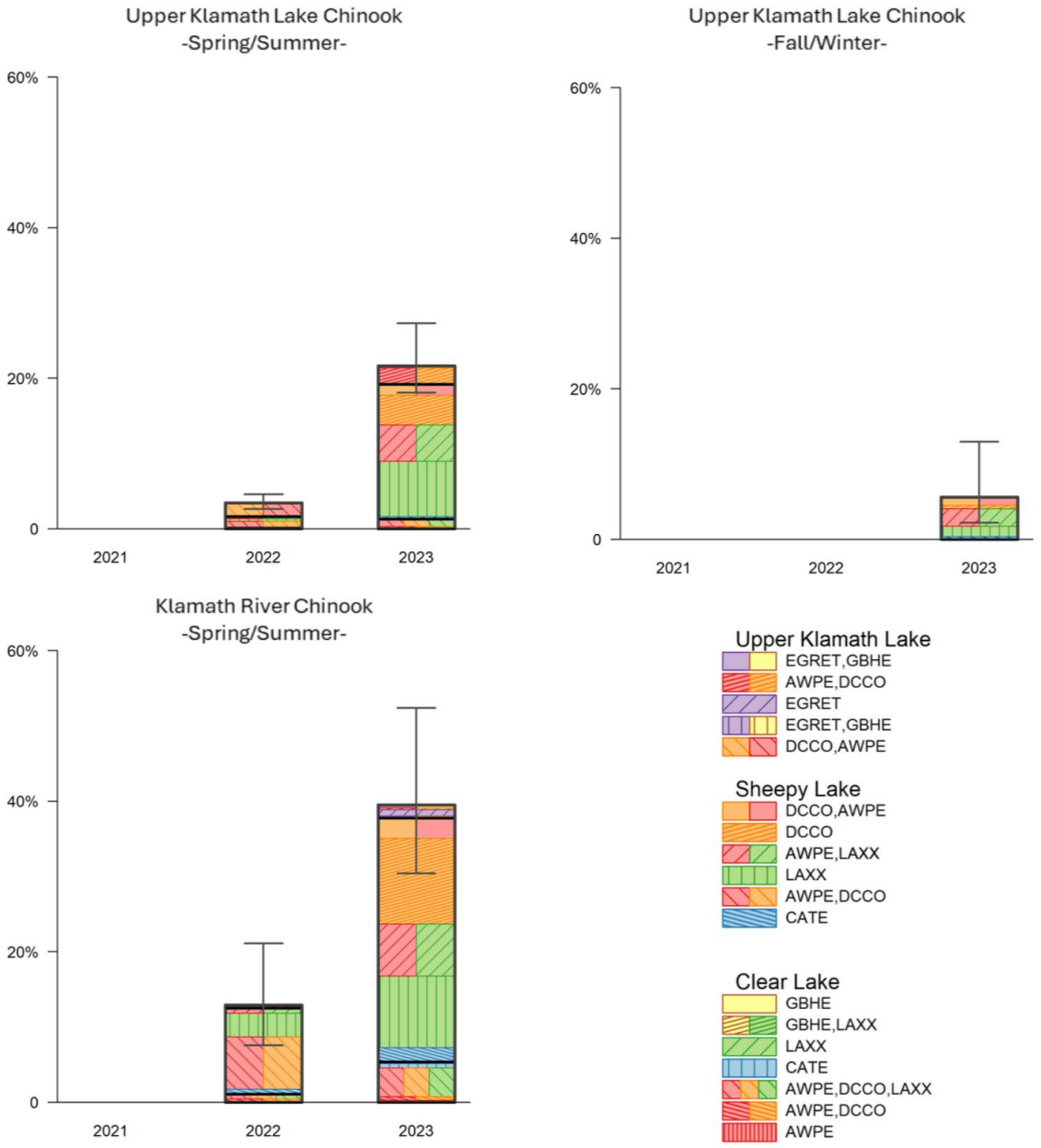

Figure 4. Estimated colony specific- and cumulative avian predation rates on PIT-tagged Chinook Salmon (Chinook) released in Upper Klamath Lake and the Klamath River during 2022–2023. Avian species include American White Pelicans (AWPE; red-colored bars), Double-crested cormorants (DCCO; orange-colored bars), Caspian terns (CATE; blue-colored bars), California Gulls and Ring-billed Gulls (LAXX; green-colored bars), Great Blue herons (GBHE; yellow-colored bars) and Great Egrets (EGRET; purple-colored bars). Mixed species colony sites are combination of species. Most colonies were located on islands in National Wildlife Refuges of Upper Klamath Lake, Clear Lake Reservoir, and on Sheepy Lake in Lower Klamath with larger heron rookeries located on the mainland. Error bars represent 95% credible intervals.

Previous published studies of avian predation in the UKB did not include predation by heron and gull colonies. Some gull colonies were scanned for adult sucker PIT tags in years past, but no tags were recovered, indicating predation rates by gulls on adult suckers were low to non-existent (Evans et al. 2022a). Data from this updated analysis also indicate that predation by gulls on adult suckers was low to non-existent, but there was evidence that gulls were consuming SARP juveniles and juvenile Chinook. 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 consumed fish by gulls were potentially dead or moribund when consumed (see also Evans et al. 2022b). 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 suckers and salmon. Unlike gulls, 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 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 released in Upper Klamath Lake, were consumed by herons, a group of piscivorous waterbirds that will continue to be studied in future UKB avian predation studies. Even after accounting for predation effects by heron and gull colonies in the present study, predation rate estimates are likely 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 or failed breeders and overwintering piscivorous waterbirds. As we learn more about new study species like herons, observations find that herons are present in the UKB year-round, although dispersed widely from their breeding colonies in fall and winter, making predation difficult to quantify.

Variation in colony sizes and locations help explain variation in estimates of avian predation rates. For instance, in 2022, cormorants and pelicans nesting in Upper Klamath Lake were following a presumed failed breeding year in 2021 and did not appear to have many individuals nesting in 2022 at the same breeding locations. Funding gap years in 2021 and 2022, however, contributed to fewer aerial surveys being conducted, so there may have been other cormorant and pelican colonies present in those years, but they were not surveyed nor scanned for fish PIT tags. The presumed lack of breeding success may also have contributed to three entirely new nesting locations in 2023, successful nesting (e.g. fledged young) at two of the three nesting locations, and higher predation rates by cormorants and pelicans in Upper Klamath Lake in 2023 compared to 2021 and 2022.

Piscivorous waterbirds in the UKB continue to be efficient samplers of SARP suckers across space and time. As managers continue to consider new release strategies and locations for SARP juvenile suckers, understanding known predation impacts can be critical, as demonstrated by SARP juvenile suckers released into Sheepy Lake. Given the investment and continued expansion of the SARP program, documenting variation in avian predation among juvenile SARP suckers provides managers with critical

information on the efficacy of management actions, such as knowing when and where to release fish to minimize predation effects. Whether or not fall/winter releases of SARP juvenile suckers result in lower predation rates, however, warrants further study.

Finally, several uncertainties remain regarding the cumulative effects of avian predation on suckers and Chinook Salmon and to what degree avian predation limits sucker recovery and future Chinook Salmon reintroduction in the UKB. Lack of recruitment, particularly in Upper Klamath Lake sucker populations, is an ongoing concern. Released SARP suckers have not been recaptured or redetected in numbers that would suggest augmenting aging spawning populations of LRS and SNS. While survival of adult LRS and SNS continues to be high, populations continue to decline and even low avian predation rates on adult populations is concerning (Evans et al. 2022a). Given that avian predation continues to be one of the highest known causes of sucker mortality, especially among juvenile SARP < 300 mm, strategies to limit predation and promote survival are critical for achieving recovery goals. A recent study found that larger release size and location of net pens can improve survival of juvenile suckers (Caldwell et al. 2023), although avian predation on larger SARP fish > 300 mm has not been studied due to small sample sizes. As observed in 2023, different SARP release and rearing strategies continue to evolve, and avian predation studies can inform effectiveness of these strategies. Future studies could continue to look at new and historical predator species and to try to estimate or identify unquantified sources of avian mortality (e.g., from non-breeding birds). As avian predation studies evolve with the SARP program, detections of live and dead fish can also be used to jointly estimate both 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 paramount to the development of effective management strategies. Addressing these remaining uncertainties in the UKB for both suckers and Chinook Salmon could be a primary goal for on-going avian predation studies.

ACKNOWLEDGEMENTS

This project was funded by the Bureau of Reclamation (BOR), with support from the U.S. Fish and Wildlife Service (USFWS). We especially thank Danielle Hereford (BOR) for assistance and support. We thank two anonymous reviewers for their reviews. We thank Mark Hereford of the Oregon Department of Fish and Wildlife for providing information on the availability of PIT-tagged Chinook Salmon in the UKB. We thank Timothy Lawes of Oregon State University and James Lawonn of Oregon Department of Fish and Wildlife for providing imagery and counts of avian colonies in 2021 and 2022. This work would not have been possible without Ria Kobernuss and Natalie Windels who assisted with colony counts, Cassidy Quistorff and Rachel Edwards who assisted with aerial photos in 2023, and Carolyn Malecha, Nick Pretto, Mark Martin, Garret Albrecht, Jacob Laurain, Haley Woodward, and John Caldwell who assisted with PIT-tag recovery efforts. Data have limited availability owing to restrictions due to sensitivity concerns. Contact Jacob Krause (jrkrause@usgs.gov) at the USGS Klamath Falls Field Station for more information. Data pertaining to SARP suckers and Chinook Salmon detected through USGS monitoring programs (including on avian colonies) are publicly available at

https://doi.org/10.5066/P16KZHPV (Krause et al. 2024). Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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APPENDICES

Appendix A.

Table A.1. Estimated average annual detection probabilities (minimum - maximum) of PIT tags on bird colonies in Upper Klamath Lake, Clear Lake Reservoir, and Sheepy Lake during 2021–2023. Values were used to account for the proportion of sucker 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.

Nesting Area	2021	2022	2023
Upper Klamath Lake	0.65 (0.59–0.87) n = 75	0.74 (0.71–0.77) n = 50	0.55 (0.52–0.65) n = 200
Clear Lake Reservoir	0.70 (0.68–0.79) n = 125	0.76 (0.72–0.80) n = 100	0.71 (0.66–0.85) n = 175
Sheepy Lake	0.50 (0.46–0.78) n = 175	0.47 (0.31–0.67) n = 150	0.61 (0.57–0.74) n = 150

Table A.2. 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 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)
Gulls	0.15 (0.11–0.21)
Herons	0.49 (0.39–0.60)

Table A.3. Numbers of PIT-tagged adult Lost River Suckers (LRS), Shortnose Suckers (SNS), Shortnose/Klamath Largescale suckers (SNS-KLS) and juvenile suckers (wild and Sucker Assisted Rearing Program {SARP}) available and subsequently recovered (in parentheses) on piscivorous waterbirds colonies in the Upper Klamath Basin during 2009–2020. Recoveries represent the total number of suckers consumed from all colonies combined. Tag recoveries only include those tags that were recovered on 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 represent minimum numbers of consumed tagged fish each year (see Methods). Dashed line (–) denotes that sample sizes of available tagged fish were < 100 and/or that PIT tag recovery did not occur at a given waterbody (Upper Klamath Lake, Clear Lake) in that year. SARP releases did not commence until 2018. Numbers are those previously reported by Evans et al. (2022).

Location	Sucker Group	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Upper Klamath Lake	Adult LRS	14,211 (27)	–	–	22,607 (76)	–	26,298 (17)	28,278 (17)	–	16,972 (63)	17,728 (69)	16,423 (9)	17,314 (2)
	Adult SNS	4,766 (25)	–	–	5,979 (75)	–	5,603 (18)	6,185 (19)	–	4,526 (61)	4,525 (41)	4,009 (5)	4,011 (2)
	Juvenile (Wild)	170 (6)	–	–	218 (6)	–	–	–	–	–	–	–	–
	Juvenile (SARP)										2,155 (30)	2,750 (50)	3,512 (113)
Clear Lake Reservoir	Adult LRS	185 (4)	299 (0)	469 (0)	513 (4)	721 (18)	674 (4)	469 (4)	833 (5)	1,080 (1)	889 (5)	1,354 (1)	957 (3)
	Adult SNS/KLS	1,010 (16)	2,445 (5)	3,363 (50)	1,220 (9)	2,070 (50)	2,375 (17)	3,153 (17)	5,415 (89)	4,249 (32)	2,887 (12)	4,140 (26)	2,034 (15)
	Juvenile (Wild)	–	–	–	–	–	–	–	–	148 (1)	–	139 (2)	111 (4)

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 2009–2023. 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).

Location [1]	Sucker Group [2]	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Clear Lake Reservoir	Adult LRS	45	18	4	42	45	29	15	7	16	16	6	9	150	19	33
	Adult SNS-KLS	187	57	77	159	162	111	38	111	60	64	41	43	183	39	137
	Juvenile (Wild)	0	0	0	4	1	0	1	0	1	1	5	7	13	8	4
	Juvenile (SARP)										1	0	2	34	1	35
Upper Klamath Lake	Adult LRS	38	1	–	72	13	29	14	–	116	136	8	5	0	3	34
	Adult SNS	39	–	–	68	1	25	18	–	99	83	2	2	0	1	44
	Juvenile (Wild)	6	0	–	8	0	1	2	–	1	0	0	0	0	0	2
	Juvenile (SARP)										32	50	87	26	143	470
Sheepy Lake	Adult LRS	1	–	–	3	0	–	–	17	11	4	3	0	8	0	3
	Adult SNS	2	–	–	1	0	–	–	10	13	6	3	1	0	0	3
	Adult SNS-KLS	0	–	–	0	0	–	–	1	0	0	0	0	0	1	0
	Juvenile (Wild)	0	–	–	0	0	–	–	2	0	0	0	7	0	0	1
	Juvenile (SARP)										1	12	41	103	51	286
Tule Lake	Adult LRS	–	–	–	–	–	1	0	0	–	0	0	0	0	–	–
	Adult SNS	–	–	–	–	–	0	0	0	–	0	2	0	0	–	–
	Adult SNS-KLS	–	–	–	–	–	1	1	3	–	0	0	1	0	–	–
	Juvenile (Wild)	–	–	–	–	–	0	0	0	–	6	2	0	0	–	–
	Juvenile (SARP)										4	1	0	0	–	–
ALL		333	78	81	363	226	199	91	151	321	357	136	205	517	266	1,052

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

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

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).

	Upper Klamath Lake Suckers				Clear Lake Reservoir Suckers		
Year	Adult LRS	Adult SNS	Juvenile Wild	Juvenile SARP	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	7.2% (2.8–16.4)	4.6% (2.6–8.4)	–
2010	–	–	–	NA	0.7% (<0.1–3.8)	0.6% (<0.1–1.8)	–
2011	–	–	–	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	4.7% (1.8–10.8)	3.8% (1.8–7.6)	–
2013	–	–	–	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	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	2.5% (<0.1–5.5)	1.4% (0.7–2.7)	–
2016	–	–	–	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	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)	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)	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)	1.2% (0.4–3.2)	2.0% (1.0–4.2)	10.5% (3.8–24.5)

Appendix B

As part of the SARP, new rearing and release strategies for hatchery reared suckers have been developed. 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 SNS and location of net pens can improve survival of SARP fish in Upper Klamath Lake (Caldwell et al. 2023). 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 2024). 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 2024). No 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 subsequently released into Upper Klamath Lake and SARP suckers reared in Lakeside Farms have not been investigated. Other groups of suckers such as those released from the Klamath Tribes Hatchery (a Klamath Tribes run facility) and juvenile suckers salvaged in A-Canal Forebay (USFWS 2024), rehabbed at the SARP hatchery, and released in Upper Klamath Lake, may also be of interest to managers concerned with avian predation effects. After gathering known release information of tagged suckers from these other rearing strategies and documenting tags recovered in each year (2021–2023), we compared predation rates for these other groups of suckers to SARP suckers released directly into Upper Klamath Lake and Sheepy Lake.

Sample sizes of Klamath Tribes Hatchery and SARP juvenile suckers reared and released using alternative strategies were typically small (Table B.1) compared with those released directly into Upper Klamath Lake (Table 2). 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 hundreds of SARP tagged suckers released into Lakeside Farms (USFWS 2024), 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 rehabbed, 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 subsequently recovered (in parentheses) on piscivorous waterbird breeding colonies in the Upper Klamath Basin during the 2021–2023 breeding seasons. Recoveries represent the total number of suckers consumed from all 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
Upper Klamath Lake	Klamath Tribes Hatchery (juvenile/adult)	1,035 (0)	913 (9)	–
	Salvage Rehabbed (juvenile/adult)	1,636 (3)	–	508 (13)
	Juvenile USGS Net Pen (SARP)	138 (2)	NA	NA
	Juvenile FWS Net Pen (SARP)	–	–	1,848 (44)
Lakeside Farms	Juvenile (SARP)	–	257 [1] (4)	391 [1] (3)

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

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 12.5% (61–23.5) during 2021–2023 (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. Predation rates on rehabbed suckers, fish captured from other waterbodies and released in Upper Klamath Lake, were substantial in 2023, but estimates were comparable to predation on SARP juveniles that were also released in UKL in 2023 (Table B.2). Predation on SARP juveniles with known tags released at Lakeside Farms ranged from <0.1% in 2022 to 5.9% (2.5–12.5) in 2023, 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.

Table B.2. Estimated cumulative avian predation rates (95% credible intervals) on PIT-tagged suckers from the Sucker Assisted Rearing Program (SARP), juvenile rehabbed (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 released 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 that year, at that location.

	Upper Klamath Lake						Lakeside	Sheepy Lake
Year	SARP Spr/Sum	SARP Fall/Win	SARP FWS Net Pen	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)