BENEFITS TO COLUMBIA RIVER ANADROMOUS SALMONIDS FROM POTENTIAL REDUCTIONS IN PREDATION BY DOUBLE-CRESTED CORMORANTS NESTING AT THE EAST SAND ISLAND COLONY IN THE COLUMBIA RIVER ESTUARY

FINAL REPORT

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This report has been prepared for the U.S. Army Corps of Engineers – Portland District for the purpose of assessing potential management actions to reduce avian predation on anadromous salmon and steelhead from the Columbia River basin.

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SUMMARY

Predation on juvenile salmonids (*Oncorhynchus* spp.) during out-migration to the Pacific Ocean is considered a factor potentially limiting the recovery of threatened and endangered anadromous salmonid populations from the Columbia River basin. We examined the potential benefits of reductions in predation by double-crested cormorants (*Phalacrocorax auritus*) nesting at the large colony on East Sand Island (rkm 8) in the Columbia River estuary to three distinct population segments (DPSs) of steelhead (*O. mykiss*), four evolutionarily significant units (ESUs) of Chinook salmon (*O. tshawytscha*), and one ESU of sockeye salmon (*O. nerka*). All eight of these salmonid populations originate from either the Columbia Basin upstream of Bonneville Dam (rkm 235) or the Upper Willamette Basin, and are listed as either threatened or endangered under the U.S. Endangered Species Act. The East Sand Island double-crested cormorant colony, averaging ca. 12,600 breeding pairs during 2007 – 2012, is the largest colony for this species in western North America, and cormorants from this colony have been documented to consume millions of salmonid smolts per year.

We estimated cormorant predation rates using recoveries of smolt passive integrated transponder (PIT) tags on the East Sand Island cormorant colony. Under the framework of a simple deterministic, age-structured, matrix population growth model for salmonid populations, we translated potential changes in smolt survival due to reductions in cormorant predation into increases in the average annual population growth rate (λ) at the level of the salmonid distinct population segement (DPS) or evolutionarily significant unit (ESU). Estimates were produced for a range of reductions in cormorant predation and for a range of levels of compensatory mortality for smolts.

Potential increases in λ (Δλ) for complete elimination of predation on smolts by East Sand Island double-crested cormorants, assuming no other mortality factors would compensate for this reduction in predation, ranged from 0.4 – 1.1% for Chinook salmon ESUs originating upstream of Bonneville Dam or from the Upper Willamette Basin, was 1.6% for the Snake River sockeye salmon ESU, and ranged from 1.8 – 2.1% for steelhead DPSs originating upstream of Bonneville Dam. If a moderate level of compensatory smolt mortality (e.g., 50%) occurred in response to a complete elimination of mortality due to cormorant predation, Δλ values would drop below 1% for Chinook and sockeye salmon ESUs, but remain 0.9 – 1.1% for steelhead DPSs.

In general, a two-thirds reduction in predation by double-crested cormorants nesting at the East Sand Island colony would produce similar levels of benefit for salmonids originating upstream of Bonneville Dam to benefits projected for the ongoing management to reduce by two-thirds the predation by Caspian terns nesting at the East Sand Island colony (USFWS 2005). Management to reduce cormorant predation would not be as efficient, however, as management to reduce Caspian tern predation in terms of benefits per managed bird due to the lower per capita impacts of cormorants on survival of salmonids originating upstream of Bonneville Dam.

As seen with other analyses of avian predation, potential benefits to ESA-listed DPSs/ESUs of Columbia Basin salmonids from reductions in predation by East Sand Island double-crested cormorants are smaller than the total expected benefits projected from all recovery actions included in the proposed management of the Federal Columbia River Power System (FCRPS). Benefits from cormorant management would not ensure recovery of any of the eight ESA-listed salmonid populations analyzed here, but are comparable to other individual recovery actions included in the 2008 Biological Opinion on the management of the FCRPS.

The robustness of these analyses would be strengthened by additional information on the degree to which other smolt mortality factors may compensate for reductions in mortality from cormorant predation. Also, the impacts of cormorant predation on survival of ESA-listed salmonids from populations originating downstream of Bonneville Dam remain poorly understood. Finally, additional measurements of on-colony deposition rates of PIT tags from PIT-tagged salmonids consumed by cormorants would further reduce uncertainty in the results presented here.

INTRODUCTION

Predation on juvenile salmonids (*Oncorhynchus* spp.) during out-migration to the Pacific Ocean is considered a factor potentially limiting the recovery of anadromous salmonid populations from the Columbia River basin that are listed under the U.S. Endangered Species Act (ESA; NOAA 2008). Colonies of piscivorous waterbirds have been highlighted as potentially important sources of mortality for juvenile salmonids across the basin (e.g., Collis et al. 2002, Evans et al. 2012). Management to reduce predation on salmonid smolts (hereafter referred to as smolts) by the world's largest colony of Caspian terns (*Hydroprogne caspia*), located on East Sand Island in the Columbia River estuary (Suryan et al. 2004), has been ongoing since 1999 (Roby et al. 2002, USFWS 2005). Resource managers are also considering management to reduce predation on smolts by waterbirds nesting at colonies in the Columbia Plateau region of eastern Washington state, based on recent assessments of predation impacts and potential benefits to ESA-listed salmonid populations (Roby 2011, Lyons et al. 2011a).

East Sand Island in the Columbia River estuary, in addition to supporting the largest Caspian tern colony, also supports the largest colony of double-crested cormorants (*Phalacrocorax auritus)* in western North America (Adkins and Roby 2010). The number of cormorants breeding in the estuary during spring and summer has increased in the last three decades from ca. 100 pairs in 1980 to over 13,000 pairs in some recent years (Carter et al. 1995, Anderson et al. 2004a, Adkins and Roby 2010). The increase was driven largely by the growth in size of the colony on East Sand Island, which now represents more than 95% of all double-crested cormorants breeding in the estuary and ca. 40% of all double-crested cormorants in western North America (Adkins and Roby 2010). (Selected information on cormorants nesting in the estuary at sites other than East Sand Island is presented in Appendix B.) Double-crested cormorants are strictly piscivorous and in the estuary juvenile salmonids have been shown to comprise a portion of cormorant diets during the breeding season (2- 28% of biomass consumed by cormorants nesting at the East Sand Island colony; Collis et al. 2002, Lyons 2010). The large size of the East Sand Island cormorant colony, along with the high daily food requirements of individual cormorants, results in millions of smolts consumed annually by cormorants nesting at this colony (Lyons 2010, Figure 1).

A variety of approaches have been used to assess the impacts of avian predators on smolt survival in the Columbia River basin, including predator diet composition (Collis et al. 2002), bioenergetics-based estimates of smolt consumption (Roby et al. 2003, Antolos et al. 2005, Maranto et al. 2010, Lyons 2010, Lyons et al. 2011b), recovery rates of smolt passive integrated transponder (PIT) tags on bird colonies (Collis et al. 2001, Ryan et al. 2003, Maranto et al. 2010, Evans et al. 2012), and projected demographic benefits to salmonid populations in the event avian predation rates were reduced (Roby et al. 2003, Antolos et al. 2005, Good et al. 2007, Lyons 2010, Maranto et al. 2010, Lyons 2011a). Of these potential indicators, population-level demographic benefits to salmonids, as quantified by the potential increase in average annual population growth rates (λ; McClure et al. 2003), have been used to justify potentially significant management actions to reduce avian predation as part of environmental analysis procedures dictated by the National Environmental Policy Act (NEPA; USFWS 2005).

In its 2008 Biological Opinion and 2010 Supplemental Biological Opinion on the proposed operation of the Federal Columbia River Power System (FCRPS) and its potential impacts to ESA-listed salmonid populations, the National Oceanic and Atmospheric Administration (NOAA) directed the federal action agencies administering the FCRPS (U.S. Army Corps of Engineers [USACE], Bonneville Power Administration [BPA], and Bureau of

Reclamation [BOR]) to analyze impacts of cormorant predation on survival of Columbia River juvenile salmonids in the estuary and develop a management plan to reduce cormorant predation, if warranted (Reasonable and Prudent Alternative [RPA] 46; NOAA 2008, 2010).

The overall goal of the analyses included in this report is to estimate benefits to salmonid populations from potential reductions in predation by double-crested cormorants nesting at the East Sand Island colony. The first objective was to identify unbiased mortality rates of threatened and endangered Columbia River salmon and steelhead (*O. mykiss*) due to cormorant predation, where appropriate data exist. The second objective was to estimate potential increases in λ for those salmonid populations from various reductions in cormorant predation. The third and final objective was to place these estimated potential benefits in the context of other recovery actions for Columbia River salmonids. The choice to express potential benefits to salmonid populations in the currency of λ was in part dictated by precedent in prior environmental analyses of impacts from avian predation (USFWS 2005, Good et al. 2007). In addition, this approach provides a useful context within which to consider the potential additive or compensatory nature of avian predation on juvenile salmonids.

These analyses consider reductions in avian predation at the level of an individual breeding colony, rather than focusing on reductions in avian predation at particular foraging sites (e.g., certain dams, pile dikes, or other locations) where the breeding status and origin of foraging birds are often unclear. Reductions in predation on juvenile salmonids by cormorants from the East Sand Island colony could be achieved by management that reduces colony size (e.g., habitat management, disturbance, or lethal control); however, if dispersal of cormorants away from East Sand Island is considered a management option, the benefits estimated here would only be accrued to the extent that cormorants do not prey on Columbia River salmonids at whatever colony location they disperse to. In addition, smolt consumption and predation rates vary considerably on an annual basis even within a single cormorant colony, making it difficult to predict impacts in any given year, regardless of colony size (Figure 1). In addition to reduction in colony size, other approaches could potentially reduce cormorant predation – for example, actions that would reduce the availability or susceptibility of smolts to predation by East Sand Island cormorants (e.g., habitat restoration for salmonids in the estuary). The estimated benefits to salmonid populations presented here are applicable regardless of what type of management action achieves reductions in cormorant predation and associated mortality of juvenile salmonids.

These analyses focus on potential benefits to ESA-listed anadromous salmonid populations and in particular those that originate upstream of Bonneville Dam (river km 235) and pass through at least one dam in the FCRPS. Cormorants also prey upon anadromous salmonids belonging to populations that are not ESA-listed, but are of cultural and economic concern, including salmonids intended to fulfill treaty and trust responsibilities to Columbia River Treaty Tribes of Native Americans. Additionally, estuary cormorants have been documented to occasionally prey upon other anadromous fishes, including coastal cutthroat trout (*O. clarki clarki*) and Pacific lamprey (*Entosphenus tridentatus*; Lyons 2010). In addition to ESA-listed salmonids, other fish populations may accrue benefits from reductions in cormorant predation, but quantifying those additional potential benefits is beyond the scope of this report.

METHODS

East Sand Island is a 21-hectare, low-lying island at river km 8 in the Columbia River estuary. The island is owned and managed by the U.S. Army Corps of Engineers, and lies within the state of Oregon. The island was naturally formed but has been heavily modified by rock revetment, dredged material disposal, and other anthropogenic activities. Double-crested cormorants initially colonized the west end of East Sand Island in 1989, when 90 pairs were observed nesting (Naughton et al. 2007). Since that time the colony has grown rapidly and expanded on and adjacent to the rock revetment that forms the southern shoreline of the western portion of the island. The average colony size during 2007 – 2012 was ca. 12,600 pairs (Adkins and Roby 2010, BRNW 2013; Figure 2).

Analysis Framework

The process we used to estimate benefits that might accrue to salmonid populations from reductions in predation by double-crested cormorants breeding at the East Sand Island colony was modeled after prior efforts to assess potential benefits from management to reduce avian predation on juvenile salmonids in the Columbia River basin (Roby et al. 2003, Antolos et al. 2005, Good et al. 2007, Lyons 2010, Maranto et al. 2010, Lyons et al. 2011a). It is challenging to project changes in survival at a juvenile life history stage into corresponding changes in recruitment into the adult breeding population (i.e., adult returns). In the Columbia River basin, a common approach to evaluating the relative benefits of a variety of salmon recovery efforts has been to employ the framework of a deterministic, age-structured, matrix population growth model (Kareiva et al. 2000). Under such a framework, improvements in survival at a given life history stage can be projected into potential improvements in the average annual population growth rate (percentage changes in λ), using just the change in survival and the population generational time (McClure et al. 2003):

$$\Delta\lambda = \left[\left(\frac{S_f}{S_i}\right)^{1/G} - 1\right] \times 100\%$$

where S_i is the initial survival rate, S_f is the final survival rate following a recovery (management) action, G is the average generational time, and $\Delta\lambda$ is the percentage change in the average annual population growth rate.

For the purposes of evaluating potential benefits from a reduction in predation by a given colony of colonial waterbirds, the salmonid life history stage can be narrowly defined to be the period of exposure to that predation, excluding other mortality factors. The initial survival rate (S_i) can then be estimated by calculating one minus the currently documented predation rate. Changes in λ can be estimated for a range of potential final survival rates (S_f), which is equivalent to one minus the expected future predation rate by the given colony. Thus, the potential benefits of different management alternatives that might produce a range of reductions in predation (and a corresponding range of increases in juvenile survival) can be quickly estimated and compared.

The estimated change in λ has been used to compare the potential efficacy of various management actions intended to help recover Columbia River salmonid populations (McClure et al. 2003), as well as to describe the potential benefits to heavily affected steelhead DPSs from reductions in Caspian tern predation in the Columbia River estuary (USFWS 2005, Good et al. 2007). Important assumptions of this approach are that increases in survival at a particular life-history stage are (1) independent of changes in survival elsewhere in the life history and (2) density-independent. We attempt to address the first assumption by presenting results for a range of compensatory mortality for smolts if mortality from avian predation was reduced (see below). Our analyses are limited in their ability to assess the possible effects of dramatically different smolt densities from those seen in recent years (e.g., differences due to hypothetical changes in hatchery production, smolt survival to downstream of Bonneville Dam, or other factors). This remains an uncertainty in our approach and that of most recovery analyses for Columbia River salmonids (McClure et al. 2003, NOAA 2008). If dramatic changes in smolt densities occurred, reanalysis using updated predation rate data would be warranted.

The conservation unit used to set most large-scale salmon and steelhead recovery objectives in the Columbia River basin is the distinct population segment (DPS), as defined by the U.S. Endangered Species Act (Waples 1991, McClure et al. 2003). Most salmonid DPSs in the Columbia River basin have unique evolutionary lineages and are referred to as evolutionarily significant units (ESUs), although this is not true for steelhead DPSs. Examples of current, large-scale recovery planning using DPSs/ESUs as the conservation unit include efforts to reduce the impacts of the Federal Columbia River Power System (USACE et al. 2007, NOAA 2008) and ongoing management to reduce predation on juvenile salmonids by Caspian terns in the Columbia River estuary (USFWS 2005, Good et al. 2007). Throughout this report, we use the term population as synonymous with DPS/ESU.

Applying the framework of a matrix population growth rate model at the DPS/ESU scale relies on the ability to estimate DPS/ESU-specific smolt survival rates prior to and following a recovery action, such as predation management. For reductions in avian predation, the effective survival can be considered to be the converse of the mortality due to avian predation (i.e., one minus the mortality) or, equivalently, the converse of the predation rate (i.e., one minus the proportion of the smolt population of interest taken by birds from a given breeding colony). Predation rates can be estimated in either one of two ways: (1) estimating smolt abundance for a given DPS/ESU at the life history stage when avian predation occurs and quantifying how many smolts of that DPS/ESU are taken, or (2) measuring the predation rate on a representative (tagged) sample of the given DPS/ESU. Estimates of smolts available to avian predators from a given breeding colony and smolts consumed by birds from that colony have been used to estimate predation rates on salmonids at the taxonomic level of species. But due to difficulties in resolving the DPS/ESU in both the estimation of smolts available and smolts consumed (Roby et al. 2003, Lyons 2010), resolution of avian predation rates to the level of DPS/ESU has not yet been accomplished using this approach. The alternative approach, estimating avian predation rates on a salmonid population using PIT-tagged smolts from that population as the representative sample group, has been the primary means employed to estimate DPS/ESU-specific avian predation rates (Collis et al. 2001, Ryan et al. 2003, Antolos et al. 2005, Good et al. 2007, Evans et al. 2012). Relying upon predation rates for a sample of PIT-tagged smolts does not require estimation of either total smolt availability or total smolt consumption at the DPS/ESU level, for either the pre- or post-management periods. Consequently, benefits accrued to salmonid populations are expressed only as changes in the population trajectory (λ), not in the absolute number of smolts consumed post-management or as the change in the number of smolts consumed due to management. Additionally, this modeling framework projects changes in smolt survival to changes in population trajectory and is not capable of estimating a change in the number of adults returning to spawn before and after management.

Salmonid Populations Considered for Analysis

Thirteen of the 19 recognized native salmon and steelhead DPSs/ESUs from the Columbia River basin are ESA-listed as either threatened or endangered. All 13 of these ESA-listed populations are potentially subject to predation by double-crested cormorants nesting on East Sand Island; however, several are not considered in our analyses. For several DPSs/ESUs, appropriate data on mortality rates due to cormorant predation were limited or unavailable (i.e., suitable samples of PIT-tagged smolts did not exist), precluding a thorough quantitative analysis. Upper Willamette River (UWR) winter-run steelhead are rarely, if ever, PIT-tagged; consequently, few data were available to assess cormorant predation on this DPS. The majority of Lower Columbia River (LCR) steelhead smolts are produced downstream of Bonneville Dam and are similarly not PIT-tagged. A minority of LCR steelhead are produced upstream of Bonneville Dam and samples of these groups are sometimes PIT-tagged; however, it is not clear that cormorant predation on these minority portions of the DPS would be representative of predation rates for the majority of smolts constituting this DPS.

For the LCR Chinook salmon (*O. tshawytscha*) and coho salmon (*O. kisutch*) ESUs, predation rate data for some components of these ESUs exist, particularly PIT-tagged sample groups of hatchery-reared smolts released downstream of Bonneville Dam (e.g., Sebring et al. 2010a, 2010b). Hatchery-reared smolts constitute a substantial fraction of the entire ESU; however, they are likely not representative of cormorant impacts on other components of the ESU, notably the naturally-spawned LCR smolts.

Along with these data limitations, managers have indicated that policy decisions on cormorant management will be based primarily upon potential benefits to DPSs/ESUs for which the majority of the population passes through the FCRPS (i.e., passes Bonneville Dam; G. Fredricks [NOAA Fisheries] and R. Willis [USACE], pers. comm.). For these reasons the LCR and UWR steelhead DPSs and the LCR Chinook and coho salmon ESUs were not considered in the primary analyses for this document; however, available information for the LCR Chinook and coho ESUs is summarized in Appendix A. A representative PIT-tagged sample of smolts from the Upper Willamette River spring-run Chinook ESU was available (those detected at Sullivan Dam at Willamette Falls), so that ESU was retained in the primary analyses. Omission from the primary analyses does not imply that cormorant impacts to these DPSs/ESUs are known to be negligible; rather, that the actual impact is not easily estimated and that policy decisions will be based primarily on potential benefits to other salmonid populations.

ESA-listed Columbia River chum salmon (*O. keta*) are also produced primarily, if not exclusively, downstream of Bonneville Dam. Only one juvenile salmonid recovered from foregut samples of cormorants collected near East Sand Island has been genetically identified as a chum salmon out of 451 samples tested (authors' unpublished data). Consequently, benefits to Columbia River chum salmon from reductions in cormorant predation during the cormorant breeding season are likely minimal and were not estimated.

We defined the juvenile salmonid life history stage of interest for the DPSs/ESUs to be analyzed using two primary criteria. First, we sought to define the life history stage as narrowly as possible, covering as short a stretch of the smolt migration period as possible, in order to minimize the prevalence of other mortality sources within the life history stage. Second, for the upstream geographic boundary of the life history stage, we used sites where it was possible to identify a sample of representative PIT-tagged smolts from the given DPSs/ESUs that would serve as the pool of available smolts from which predation rates would be estimated. Using these criteria, the available pool of smolts from each DPS/ESU originating upstream of Bonneville Dam was defined as those PIT-tagged smolts known to pass downstream of Bonneville Dam (rkm 235). For Upper Willamette River Chinook salmon, the available smolt pool consisted of PIT-tagged smolts detected at Sullivan Dam on the Willamette River in Oregon City, Oregon (203 river km from the Columbia River mouth). The resulting life history stage can be considered to be the period in which smolts are present downstream of these two enumeration points until they enter the Pacific Ocean at the mouth of the Columbia River.

Predation Rate Estimates

Samples used for predation rate estimation: For DPSs/ESUs originating from the Snake River basin, a substantial portion of smolts are captured and loaded onto barges or trucks and transported downstream of Bonneville Dam, where they are released back into the river. For these DPSs/ESUs, this practice results in a partitioning of the smolt population into two groups (transported versus in-river migrants) that have experienced quite different migration conditions, and it is possible that predation rates by East Sand Island cormorants might be different for the two groups. To investigate this possibility, we reviewed published and unpublished comparisons of PIT tag recovery rates on the East Sand Island cormorant colony for PIT-tagged samples of transported and in-river migrants (Ryan et al. 2003, Sebring et al. 2010a, 2010b; A. Evans, unpublished data). Differences in predation rate sometimes occurred between transported and in-river yearling Chinook, sub-yearling Chinook, and steelhead (trends for sockeye have not been investigated); however, the direction of the differences was not consistent across years or often even within a given year. Because in-river migration conditions are quite variable from one year to the next or even within years (due to variable flows, hydrosystem operational decisions, and other factors), it should not be surprising that comparisons of relative predation rates between in-river migrating smolts and transported smolts do not show a consistent pattern. Because of the lack of a clear and consistent trend in PIT tag recovery rates between transported and in-river smolts, and because in-river smolts were more representative of the run as a whole (e.g., transportation only occurs during a portion of the annual outmigration), we opted to base our predation rate estimates on data from in-river migrants only.

Each ESA-listed DPS/ESU that we examined was potentially further partitioned between hatchery-reared and naturally-spawned ("wild") smolts. In each year and for each DPS/ESU where an adequate sample of PIT-tagged smolts ($N \geq 500$) was available for both wild and hatchery rearing types, we estimated independent tag recovery rates for each group. In only 3 of 15 potential comparisons (across 2007 – 2010) were significant differences in tag recovery rates observed between rearing types, with wild steelhead more susceptible to cormorant predation in two comparisons and hatchery-reared yearling Chinook salmon more susceptible in the other. Given that differences between cormorant predation rates on hatchery and wild smolts lacked a consistent trend, and that ESA-listed DPS/ESU definitions include both hatchery and wild types, we opted to pool hatchery and wild smolts for the estimation of cormorant predation rates.

For all DPSs/ESUs originating from upstream of Bonneville Dam plus the UWR spring-run Chinook ESU, PIT-tagged smolts represented an opportunistic sample of the entire DPS/ESU smolt population. Fish used to determine cormorant predation rates were PIT-tagged as part of other studies within the basin. In all cases, we assumed the PIT-tagged sample used was representative of the run as a whole.

The mean sample size enumerated at either Bonneville Dam or Sullivan Dam and used to calculate annual PIT tag recovery rates was 10,114 smolts per DPS/ESU (range: 510 – 40,023 smolts). We estimated annual PIT tag recovery rates for each DPS/ESU only when at least 500 smolts were enumerated in the available pool. Our study period covered the years 2007– 2012, although adequate samples sizes were not available for Snake River sockeye salmon in either 2007 or 2008.

Some smolt mortality occurs between the points where smolts were enumerated (Bonneville Dam, rkm 235, and Sullivan Dam, 203 km from the Columbia River mouth) and the upper extent of the foraging range of cormorants nesting on East Sand Island in the estuary. Cormorant foraging and roosting aggregations have been observed in April and May as far upstream as rkm 75, but not consistently upstream of that point; it is unknown if these observations were of birds actively nesting on East Sand Island (Collis et al. 2000, Lyons et al. 2007). Foraging areas of cormorants known to be breeders at the East Sand Island colony later in the season (June and July) do not extend as far into the upper estuary, with observed activity confined to downstream of rkm 60 (Anderson et al. 2004b). Survival of smolts tagged with acoustic transmitters and released downstream of Bonneville Dam has been observed to be > 90% at least to rkm 86 (McMichael et al. 2010). Using a pool of available smolts enumerated at either Bonneville or Sullivan dams, and not discounting the size of that pool by the mortality that occurs prior to smolts arriving within the foraging area of East Sand Island cormorants, results in a slight underestimation of mortality rates due to cormorant predation. We confirmed this was a small effect by comparing PIT tag recovery rates on East Sand Island from steelhead and yearling Chinook smolts detected at Bonneville Dam with PIT tag recovery rates of those smolts detected in NOAA's estuary trawl operation (conducted at rkm 65 – 84; Ledgerwood et al. 2004). Tag recovery rates of smolts detected in the trawl trended higher but were rarely significantly greater than those for smolts detected at Bonneville Dam and subsequently recovered on the East Sand Island cormorant colony (A. Evans, unpublished data). Detections of PIT-tagged smolts by the trawl would have been a preferable dataset to use to estimate tag recovery and predation rates, but low capture and detection efficiency by the trawl results in an insufficient sample size to produce DPS/ESU-specific estimates of cormorant predation rates. We proceeded with the analysis based on detections at Bonneville and Sullivan dams, despite this small bias, consistent with prior analyses of predation on smolts by Caspian terns nesting at East Sand Island (Good et al. 2007).

Smolt PIT tag recovery at the East Sand Island cormorant colony: To estimate what portion of each PIT-tagged sample of smolts was taken by double-crested cormorants nesting on East Sand Island, scanning for PIT tags deposited by cormorants on their breeding colony was conducted by NOAA Fisheries and the Pacific States Marine Fisheries Commission (S. Sebring, J. Zamon, and colleagues) using the methods of Ryan et al. (2003), after nesting cormorants had dispersed following each breeding season (August to November).

Converting PIT tag recovery rates into predation rates: Not all smolt PIT tags deposited by cormorants on the colony are subsequently detected by researchers due to tag erosion, damage to tags, or other factors. Estimates of detection efficiency of deposited PIT tags were made using the sown control tag method of Evans et al. (2012).

Colony-based PIT tag recoveries, corrected for detection efficiency, still do not directly account for all PIT-tagged fish consumed by birds nesting at that colony, however, as adult birds may deposit some proportion of ingested PIT tags (via regurgitation or defecation) at loafing or other sites away from the colony, or PIT tags may be damaged prior to egestion at either on- or off-colony locations. To correct for this phenomenon, an on-colony PIT tag "deposition rate", or the proportion of ingested PIT tags that were deposited at the colony and remained functional following ingestion and egestion, is required.

PIT tag deposition rates have been measured for Caspian terns using two different methods, at two different breeding colonies, and in three separate years (Collis et al. 2007). No such comprehensive study exists for double-crested cormorants; however, in 2011methods were developed at the East Sand Island cormorant colony to estimate PIT tag deposition rates. PIT-tagged fish were thrown from an observation blind into an area of actively nesting cormorants (the blind was immediately adjacent to the cormorant nests), and some of the thrown fish were observed to be picked up off the ground and consumed, providing an inventory of PIT-tagged fish that were known to have been consumed by East Sand Island cormorants. , In 2012, a more robust deposition experiment was conducted at three different observation blinds and at three different stages of the nesting period (2 May, 24 May, and 13 June). Double-crested cormorants consumed a total of 301 PIT-tagged fish during the 2012 experiments. The resulting estimate of on-colony deposition rate for cormorants nesting at East Sand Island in 2012 was 44% (95% confidence interval: 36-51%). This corresponds to 44% of all smolt PIT tags consumed by East Sand Island cormorants being deposited on the cormorant colony still functioning and available for recovery using the methods of Evans et al. (2012). Results provided in this revised report applied the estimate of on-colony deposition rate from the 2012 study (44%) to all study years (2007-2012), as it provided the most robust estimate currently available. Additional PIT tag deposition rate studies, however, could improve the accuracy of the 2012 estimates and, depending on the results, the level of correction applied to past (i.e., 2007-2011) and future predation rate estimates.

Predation rates were estimated using a multi-step modeling approach that allows for potential variability in PIT tag recoveries, detection efficiencies, and deposition rate across the breeding season, with confidence intervals estimated using a bootstrapping simulation technique (after Evans et al. 2012). Annual predation rates were averaged over the years 2007 – 2012 to obtain a single estimate of predation rate for each DPS/ESU. Given a large degree of inter-annual variability in predation rates (see results below), this average predation rate is a representation of predation rates just in the recent years of our study; average predation rates for alternative time periods, and potential benefits of management extrapolated from them, might be somewhat different.

Average predation rates were used to calculate the initial survival (Si; equal to 1 – average predation rate) for the $\Delta\lambda$ calculation described above. Changes in averages of annual predation rates are appropriate quantities to translate into benefits to λ, the *average* annual population growth rate. The correct interpretation of estimated benefits to lambda is the potential benefit of a reduction in predation once the management action to produce that reduction is fully completed and predation has stabilized at a new (lower) level. The large interannual variability in predation rates may result in estimated benefits being demonstrable only over longer time periods (5-10 years or longer).

Reductions in Predation and Potential Compensatory Responses

In order to offer managers an assessment of a variety of potential management scenarios, we calculated changes in the population trajectory ($\Delta\lambda$) for multiple levels of reduction in cormorant predation rates. Complete elimination of cormorant predation (100% reduction) was considered to describe the maximum potential benefit possible from management action. Intermediate levels between this maximum and no action (25%, 50%, and 75% reductions) were considered to provide estimated benefits for a range of management effort.

Avian predation on juvenile salmonids from a given DPS/ESU may be additive mortality, resulting in lowered recruitment into future spawning cohorts regardless of other mortality factors. Alternatively, a reduction in smolt mortality due to cormorant predation may be compensated for by other sources of mortality (e.g., other predators) at other life history stages prior to spawning (compensatory mortality).

The degree to which avian predation on juvenile salmonids in the Columbia River basin is additive versus compensatory is currently unknown. Previous evaluations of avian predation have all acknowledged this uncertainty and dealt with it in different ways. Roby et al. (2003) and Lyons (2010) estimated benefits to salmonids from reductions in losses to avian predators for the range of possible compensation (0% to 100%), while Antolos et al. (2005) and Good et al. (2007) calculated benefits based only on the assumption of 0% compensatory mortality (completely additive mortality) and acknowledged that actual benefits would be less if compensation occurred. A recent analysis was performed to assess the potential benefits if avian predation on salmonids in the Columbia Plateau region were reduced (Lyons et al. 2011a). Lyons et al. (2011a) estimated benefits for a range of compensation (0% to 75%); however, for comparison purposes the fully additive case (0% compensation) was the primary scenario considered.

In recent years, strong evidence has emerged that indicates smolt mortality from avian predation is neither completely additive nor completely compensatory. Preliminary results on a small sample of $SR_{S/S}$ Chinook salmon smolts suggested that fish in relatively poor physical condition, as indicated by bacterial infections and incomplete smoltification, were more susceptible to avian predation in the estuary (Schreck et al. 2006). A more comprehensive study of SR steelhead conducted on the Columbia Plateau indicated that fish in poor condition, as evidenced by external signs such as de-scaling, fin damage, disease, and other factors, were significantly more susceptible to avian predation than apparently healthy smolts (Hostetter et al. 2012). This disproportionate consumption of fish in degraded condition suggests that some portion of the smolt mortality caused by avian predators would likely be compensated for by other mortality factors if avian predation were eliminated. The Hostetter et al. (2012) study also documented lower, but still substantial, levels of predation on smolts seemingly in excellent condition, and noted that smolts in poor condition were only a small minority of all smolts in-river. These observations suggest that some mortality from avian predation is additive, or not likely to be compensated for by other sources of mortality.

Additional information that suggests that mortality due to avian predation is neither fully additive or fully compensatory is the results from NOAA's alternative barge study, where paired groups of PIT-tagged steelhead and yearling Chinook smolts were transported downstream and released in two locations: (1) the location of current practice just downstream of Bonneville Dam, and (2) downstream of Astoria, Oregon (rkm 10) at night and on an outgoing tide (Marsh et al. 2011). For the releases just downstream of Bonneville Dam, smolts were fully exposed to predation by double-crested cormorants and other avian predators nesting on East Sand Island once they arrived in the lower estuary. For groups released near Astoria, smolts were exposed to avian predators nesting on East Sand Island for a much shorter period of time, and experienced significantly lower mortality due to avian predation. Groups that experienced lower avian predation rates in the estuary, however, returned as adults at higher rates only some of the time (Marsh et al. 2011). Comparisons of survival between paired groups of smolts released under different circumstances (e.g., different release locations and arrival timing to the ocean) are not perfect tests of compensatory mortality; however, such differences between groups were relatively small in the alternative barge study and should not be completely ignored. The differences in rates of smolt mortality produced by reducing exposure of some groups to avian predators in the estuary were compensated for by other mortality factors at quite variable rates, casting additional doubt on assumptions that avian predation in the estuary is either fully additive or fully compensatory.

We calculated potential benefits to salmonid DPSs/ESUs for a range of compensation – 0%, 25%, 50%, and 75% (100% compensation would result in zero net benefit from a reduction in avian predation). All perspective reductions in predation rate were devalued by the converse of the compensation rate to obtain the actually realized reduction in mortality rate (i.e. predation rates were multiplied by (100% - compensation rate)/100%). Other recovery efforts for Columbia River salmonids are typically evaluated assuming 0% compensation (NOAA 2008) and results based on that assumption are prioritized for discussion in this report for comparison purposes. Given the studies discussed above that suggest predation is neither completely additive nor completely compensatory, our results for 25 – 75% compensation represent a biologically more likely range of potential benefits, however. Considering a range of possible compensatory mortality in this manner overcomes one of the major assumptions of the modeling framework – that increases in survival at a particular life-history stage are independent of changes in survival elsewhere in the life history.

Estimating Benefits

Changes in λ were calculated using average generational times for each DPS/ESU from McClure et al. (2003; provided here in Table 3), with the exception of SR sockeye salmon, where measuring generational time has been difficult due to the small number of adult returns. For this ESU, we used the age composition of adult sockeye sampled at Bonneville Dam (mean age = 3.0 years; Torbeck et al. 2008), which consists primarily of fish from the Upper Columbia River, as a surrogate measure of generational time for SR sockeye.

Sampling errors were available for some quantities (e.g., PIT tag predation rates) but not others (e.g., generational times), so we did not attempt to estimate confidence intervals for projected improvements in λ, following the lead of earlier efforts (Roby et al. 2003, USFWS 2005, Antolos et al. 2005, Good et al. 2007, USACE et al. 2007, Lyons et al. 2011a).

An example calculation of Δλ is as follows, for the hypothetical management objective of a 50% reduction in predation on a DPS experiencing an 8% average predation rate and having a generational time of 3.0 years, and with other mortality factors compensating for 25% of the reduction in cormorant predation. The initial survival rate to cormorant predation (S_i) is 1 – (0.08) = 0.92 or 92%. The final predation rate before considering compensation is 50% of the 8% average predation rate, or 4%. With 25% compensation the effective change in mortality rate from reductions in cormorant predation is [(100% – 25%)/100%] * 4% = 3%. Consequently, the initial survival rate is increased from 92% to a final survival rate (S_f) of 95% under this scenario. Inserting these quantities into the McClure et al. framework equation gives an approximate 1% increase in λ:

$$\Delta\lambda = \left[\left(\frac{S_f}{S_i}\right)^{1/G} - 1\right] \times 100\%$$

$$= \left[\left(\frac{0.95}{0.92}\right)^{1/3.0} - 1\right] \times 100\%$$

$$= 1.1\%$$

RESULTS

Estimates of predation rates by East Sand Island double-crested cormorants on salmon and steelhead DPSs/ESUs varied considerably during the 2007 – 2012 study period, with maximum annual values typically three to five times greater than minimum annual values (Tables 1 and 2). Means of the annual predation rate estimates ranged from 2.5% for Upper

Willamette River spring-run Chinook salmon to 9.8% for Snake River steelhead (Table 2). Predation rates were generally greatest for the three steelhead DPSs examined (Upper Columbia River, Snake River, and Upper Willamette River DPSs), consistent with predation rates by Caspian terns throughout the Columbia River basin (Collis et al. 2001, Lyons 2010, Evans et al. 2012). Cormorant predation rates on Snake River sockeye salmon (4.5%) fell within the range seen for the various Chinook salmon ESUs (2.5 – 4.9%).

Potential increases in the average annual population growth rate (λ) for complete elimination of predation by double-crested cormorants nesting on East Sand Island, and assuming no other mortality factors compensated for this reduction in mortality due to cormorant predation, ranged from 0.4 – 1.1% for Chinook salmon ESUs, was 1.6% for the Snake River sockeye salmon ESU, and ranged from 1.8 – 2.1% for steelhead DPSs (Table 4). These estimates represent the theoretical maximum possible benefits for salmonid populations if cormorant management is maximized and mortality from cormorant predation is fully additive. If a moderate level of compensation (e.g., 50%) occurred for this case of complete elimination of cormorant predation, Δλ values would drop below 1% for Chinook salmon and sockeye salmon ESUs (0.2 – 0.8%), but remain 0.9 – 1.1% for steelhead DPSs. If the reduction in cormorant predation was intermediate (50%) and mortality due to cormorant predation was considered fully additive, Δλ values would again drop below 1% for Chinook salmon and sockeye salmon ESUs, but remain 0.9 – 1.1% for steelhead DPSs.

Benefits to salmonid populations (Δλ values) from reductions in predation by double-crested cormorants nesting on East Sand Island were comparable to benefits projected for other recovery efforts in progress or proposed. For comparison purposes, we assumed that smolt mortality from cormorant predation is fully additive, and estimated that a 67% reduction in cormorant predation would produce a cumulative benefit (summed $\Delta\lambda$ values) of 4.0% for the three upper basin steelhead DPSs (see Table 5). This is comparable to the estimated cumulative benefit (summed $\Delta\lambda$ values) of 5.7% that can be projected for a similar level of reduction in predation by the East Sand Island Caspian tern colony. (To obtain this estimate, we used the available data on detection efficiency and deposition rate for Caspian terns nesting on East Sand Island and also assumed that mortality from tern predation is 100% additive [USFWS 2005, Good et al. 2007, Collis et al. 2007; see Table 5]). The maximum potential benefits from management to reduce predation by double-crested cormorants nesting on East Sand Island for all of the individual salmonid DPSs/ESUs considered here (range = 0.4 – 2.1%, assuming 0% compensation) were generally comparable to those based on analyses of reductions in avian predation by other waterbird colonies under similar assumptions. The exception was that no salmonid DPS/ESU could benefit as much from reductions in predation by cormorants nesting on East Sand Island as Upper Columbia River steelhead could potentially benefit from reductions in avian predation (Caspian terns, double-crested cormorants, and gulls combined) in the Columbia Plateau region ($\Delta\lambda$ = 5.0%; Lyons et al. 2011a).

DISCUSSION

Juvenile salmonid mortality rates due to predation by double-crested cormorants nesting at East Sand Island were comparable to a number of other mortality factors documented within the basin. For example, juvenile dam passage survival rates (concrete survival) ranged from 95.3 – 99.5% (mean 98.2%) for steelhead, 95.7 – 98.7% (mean 96.9%) for yearling Chinook salmon, and 94.0 – 97.9% (mean 95.4%) for subyearling Chinook salmon as measured at various dams across the FCRPS during 2010 – 2012 performance standard tests (BPA et al. 2013, NOAA

2013). Average annual cormorant predation rates on the three steelhead DPSs we considered (7.7 – 9.8%) were greater than typical mortality at individual FCRPS dams for all steelhead pooled (0.5 – 4.7%). Average annual predation rates for yearling Chinook ($SR_{S/S}$, UCR_{Sp}, and UWR_{Sp} ESUs) ranged from 1.9 – 4.8%, comparable to the mortality seen at dams for all yearling Chinook pooled (1.3 – 4.3%). The average annual predation rate for the Snake River fall Chinook ESU (3.2%) fell within the range of mortality seen at dams for all subyearling Chinook pooled (2.1 – 6.0%). These general comparisons suggest that cormorant predation is a mortality factor of similar importance to salmonid populations to that of a single dam, or perhaps of greater importance than a single dam for steelhead. The cumulative mortality of dam passage for those populations that pass through multiple dams, however, likely exceeds the mortality due to cormorant predation.

Interpreting benefits to the population trajectory, or average annual population growth rate (λ), of salmonid DPSs/ESUs due to reductions in avian predation is not necessarily intuitive and should be considered in a variety of contexts. The potential benefits we describe here are percent increases in λ; the new value of λ (λ_{new}) can be calculated based on the old value (λ_{old}) and the calculated benefit ($\Delta\lambda$, expressed as a percentage):

$$\lambda_{new} = \lambda_{old} \times (1 + \frac{\Delta\lambda}{100})$$

For example, if $\lambda_{old} = 0.93$ and $\Delta\lambda = 3.3\%$, then

$$\lambda_{new} = 0.93 \times (1 + \frac{3.3}{100}) = 0.93 \times 1.033 = 0.9607.$$

For a stable population, $\lambda = 1$. When $\lambda > 1$, the population is increasing and for $\lambda < 1$, the population is declining. For salmonid ESUs in decline, the management objective is to increase λ to some level > 1 (McClure 2003, NOAA 2008, 2010).

A useful context in which to evaluate the benefits calculated in this report is to compare them to the potential benefits calculated for management currently underway to reduce predation by Caspian terns nesting at East Sand Island and for potential management actions that could reduce avian predation on smolts in the Columbia Plateau region (Table 5). In 2005, a management plan and environmental impact statement (EIS) were completed that called for a reduction of ca. 67% in the size of the East Sand Island Caspian tern colony (down to approximately 3,125 breeding pairs from a baseline size of ca. 10,000 pairs) to reduce predation on Columbia Basin salmonid populations. Benefits for steelhead DPSs were calculated as part of the development of that plan using data on PIT tag recovery rates (USFWS 2005, Good et al. 2007). Similar estimates were also produced for the FCRPS management plan and biological assessment, but drew on bioenergetics-based, species-level estimates of predation rates on salmonid smolts (USACE et al. 2007, NOAA 2008).

Analyses have been recently completed that estimate potential benefits to upper basin salmonid populations if management of various degrees was undertaken to reduce avian predation in the Columbia Plateau region. Those analyses considered management to reduce predation on smolts by some or all of the piscivorous waterbirds nesting at five colonies in the Columbia Plateau region: the Caspian tern colony at Goose Island in Potholes Reservoir (near Othello, WA); the Caspian tern colony at Crescent Island (near Pasco, WA); the Caspian tern colony in the Blalock Island Complex (mainstem Columbia River); the double-crested cormorant colony at Foundation Island (also near Pasco, WA); and a mixed species gull colony (*Larus* spp.) at Miller Rocks (near Maryhill, WA).

Our estimates of potential benefits from reducing predation by the East Sand Island double-crested cormorant colony are similar to those projected for reducing predation by the East

Sand Island Caspian tern colony or reducing predation at several Caspian tern colonies in the Columbia Plateau region. Reductions in smolt predation by East Sand Island cormorants would not achieve as great a benefit for any single DPS/ESU as would reductions in avian predation in the Columbia Plateau region for the Upper Columbia River steelhead DPS, but would instead offer greater cumulative benefits for salmonid DPSs/ESUs from across the Columbia River basin. For example, reductions in avian predation in the Columbia Plateau region would primarily benefit the six ESA-listed salmonid DPSs/ESUs originating from the Snake River and Upper Columbia River basins, while management to reduce predation by cormorants nesting at the East Sand Island colony would benefit all eight of the ESA-listed DPSs/ESUs considered here, as well as potentially benefitting several of the ESA-listed DPSs/ESUs produced primarily downstream of Bonneville Dam (e.g., Appendix A). A two-thirds reduction in predation by double-crested cormorants nesting at the East Sand Island colony would likely produce a similar level of benefit for salmonid populations originating upstream of Bonneville Dam as can be projected for ongoing management to reduce predation by East Sand Island Caspian terns by a similar (two-thirds) proportion (Table 5).

As seen with other analyses of avian predation, potential benefits to ESA-listed salmonid DPSs/ESUs from reductions in predation by double-crested cormorants nesting at East Sand Island are smaller than the total cumulative expected benefits projected from all recovery actions included in the FCRPS BiOp (Table 5). Benefits from cormorant management at East Sand Island are comparable, however, to most individual recovery actions included in the BiOp (NOAA 2008).

Management to reduce predation on juvenile salmonids originating upstream of Bonneville Dam by double-crested cormorants from the East Sand Island colony would not be as efficient on a per managed bird basis as management focused on the East Sand Island Caspian tern colony (Table 5; Good et al. 2007, Lyons et al. 2011a). For example, estimated benefits from proportionally similar (e.g., two-thirds) reductions in predation by the East Sand Island Caspian tern colony and the East Sand Island double-crested cormorant colony are quite similar. The cormorant colony is larger than the tern colony, however, so to achieve a similar proportional reduction in smolt predation, predation by a greater number of cormorants must be managed (see Table 5). Despite the larger body size of double-crested cormorants compared to Caspian terns (3-4 times greater) and correspondingly greater food requirements, per capita predation rates on smolts originating upstream of Bonneville Dam by the East Sand Island double-crested cormorant colony are less than those for the East Sand Island Caspian tern colony, and much less than those for the Caspian tern colonies in the Columbia Plateau region (Evans et al. 2012). This lower per capita smolt consumption by East Sand Island cormorants is largely a result of salmonids comprising a smaller portion of the cormorant diet at this location than for Caspian terns nesting anywhere within the Columbia River basin (Lyons 2010, Lyons et al. 2011b).

While performing these analyses, we faced several uncertainties where data were lacking. Perhaps the most critical uncertainty for assessing potential benefits to salmonid populations from reduced cormorant predation on juveniles is the degree to which other mortality factors later in the life history might compensate for reductions in mortality due to cormorant predation. Recovery planning for Columbia River salmon and steelhead is largely predicated on the paradigm that delivering more juveniles to the ocean will result in greater numbers of returning adults (e.g., NOAA 2008). A number of stakeholder groups within the basin have pointed out, however, that it is unreasonable to expect a one-to-one relationship (fully additive mortality) between increases in juvenile survival and smolt to adult return rates (e.g., R. Kiefer, Idaho Department of Fish and Game, pers. comm.). Efforts to analyze the relationship between avian predation rates and ultimate salmonid survival (e.g., adult return rates) would greatly improve our understanding of the additive and/or compensatory nature of avian predation.

Another uncertainty critical to accurately estimating predation rates by double-crested cormorants nesting at East Sand Island is the on-colony deposition rate of ingested PIT tags by cormorants. Results from a study conducted in 2012 were applied to analyze predation rates in multiple years (2007-2012). The robustness of our results would benefit from additional studies to measure on-colony PIT tag deposition rates by cormorants nesting on East Sand Island and evaluate inter-annual variation in those rates.

Cormorant predation rates on several ESA-listed DPSs/ESUs were not addressed in this analysis, primarily due to data limitations. We used the limited data currently available to assess impacts to Lower Columbia River (LCR) Chinook and coho salmon ESUs in Appendix A; however, potential benefits from reductions in cormorant predation on other listed DPSs/ESUs cannot be assessed at this time.

Despite these uncertainties, it is clear that actions to reduce predation on juvenile salmonids by double-crested cormorants nesting at East Sand Island will not by themselves recover ESA-listed anadromous salmonid populations originating upstream of Bonneville Dam. Reductions in cormorant predation in the estuary could, however, result in increases in salmonid population growth rates comparable to some other salmonid recovery efforts in the Columbia River basin, particularly for steelhead populations. Reducing cormorant predation could also benefit ESA-listed salmonid populations originating downstream of Bonneville Dam, non-listed salmonid populations that also have significant cultural and economic value, and other species of conservation concern that we did not consider (e.g., Pacific lamprey).

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Table 1. Annual predation rate (PR) estimates by East Sand Island double-crested cormorants on selected Columbia Basin salmon and steelhead populations listed under the U.S. Endangered Species Act (ESA), with 95% confidence intervals (95% CI) and sample sizes (n). Salmonid populations are broken down into evolutionarily significant units (ESU) for salmon and distinct population segments (DPS) for steelhead. Predation rate estimates are based on the recovery of smolt PIT tags deposited by cormorants at the East Sand Island colony, are corrected for on-colony PIT tag detection efficiencies (after Evans et al. 2012) and use an on-colony PIT tag deposition rate of 44% (see Methods) . Availability of PIT-tagged smolts was assessed at Bonneville Dam (rkm 235) for Snake River (SR), Upper Columbia River (UCR), and Middle Columbia River (MCR) DPSs/ESUs, and at Sullivan Dam on the Willamette River (203 km from the Columbia River mouth) for the Upper Willamette River (UWR) spring-run Chinook salmon ESU. We estimated annual predation rates for each DPS/ESU when at least 500 smolts were enumerated in the available pool.

Species	DPS/ESU	2007 PR 95% CI n	2008 PR 95% CI n	2009 PR 95% CI n	2010 PR 95% CI n	2011 PR 95% CI n	2012 PR 95% CI n
Chinook	$SR_{S/S}$	1.9% 1.4 – 2.4% 23,830	3.9% 2.9 – 4.9% 11,425	7.7% 6.1 – 9.3% 17,396	6.1% 5.0 – 7.2% 38,441	4.8% 3.6 – 6.0% 6,557	4.2% 3.2 – 5.2% 17,929
	SR_{F}	1.6% 0.3 – 2.9% 2,005	3.0% 2.3 – 3.7% 24,136	5.1% 4.0 – 6.2% 16,314	4.4% 3.4 – 5.4% 17,974	2.2% 1.6 – 2.8% 12,327	3.0% 2.2 – 3.8% 10,742
	UCR_{Sp}	2.9% 1.1 – 4.7% 2,268	3.9% 1.8 – 6.0% 1,662	2.9% 1.3 – 4.5% 2,064	3.7% 2.6 – 4.8% 5,972	5.9% 2.1 – 9.7% 704	2.3% 1.2 – 3.4% 3,227
	UWR_{Sp}	0.9% 0.1 – 2.0% 1,505	3.7% 1.9 – 5.5% 2,509	1.5% 0.8 – 2.2% 5,573	4.1% 0.3 – 7.9% 510	0.3% 0.1 – 1.0% 1,119	0.6% 0.1 – 1.1% 3,731

Table 1 (continued).

Species	DPS/ESU	2007 PR 95% CI n	2008 PR 95% CI n	2009 PR 95% CI n	2010 PR 95% CI n	2011 PR 95% CI n	2012 PR 95% CI n
Sockeye	SR	n = 168	n = 187	6.3% 3.7 – 8.9% 1,845	2.7% 1.0 – 4.4% 1,382	5.0% 1.9 – 8.1% 826	4.0% 1.9 – 6.1% 1,457
Steelhead	SR	3.9% 2.6 – 5.2% 6,391	16.8% 13.5 – 20.1% 19,572	18.5% 15.2 – 21.8% 23,311	8.5% 7.0 – 10.0% 40,024	6.0% 4.4 – 7.6% 7,028	5.4% 3.8 – 7.0% 4,768
	UCR	3.8% 2.0 – 5.6% 3,042	6.9% 4.5 – 9.3% 2,513	7.9% 5.3 – 10.5% 2,265	7.6% 6.1 – 9.1% 12,284	12.6% 9.2 – 16.0% 2,419	7.2% 4.9 – 9.5% 3,357
	MCR	3.0% 1.4 – 4.6% 2,234	15.5% 11.2 – 19.8% 2,291	16.6% 12.5 – 20.7% 2,700	9.2% 7.3 – 11.1% 8,515	8.5% 4.4 – 12.6% 865	3.4% 1.0 – 5.8% 1,084

Table 2. Mean annual predation rate estimates by East Sand Island double-crested cormorants on selected Columbia Basin salmon and steelhead populations listed under the U.S. Endangered Species Act (ESA).[1] Salmonid populations are broken down into evolutionarily significant units (ESU) for salmon and distinct population segments (DPS) for steelhead. Predation rate estimates are based on the recovery of smolt PIT tags deposited by cormorants at the East Sand Island colony, are corrected for on-colony PIT tag detection efficiencies (after Evans et al. 2012) and use an on-colony PIT tag deposition rate of 44% (see Methods). Availability of PIT-tagged smolts was assessed at Bonneville Dam (rkm 235) for Snake River (SR), Upper Columbia River (UCR), and Middle Columbia River (MCR) DPSs/ESUs, and at Sullivan Dam on the Willamette River (203 km from the Columbia River mouth) for the Upper Willamette River (UWR) spring-run Chinook salmon ESU.

	Chinook				Sockeye	Steelhead		
	$SR_{S/S}$	SR_F	UCR_{Sp}	UWR_{Sp}	SR	SR	UCR	MCR
Mean Annual Predation Rate 2007 – 2012	4.8%	3.2%	3.6%	1.9%	4.5%	9.8%	7.7%	9.4%
Range in Annual Predation Rate	1.9 – 7.7%	1.6 – 5.1%	2.3 – 5.9%	0.3 – 4.1%	2.7 – 6.3%	3.9 – 19%	3.8 – 13%	3.0 – 17%

[1]Five ESA-listed Columbia River salmon and steelhead populations are not listed here. Lower Columbia River (LCR) and Upper Willamette River steelhead DPSs lack representative samples of PIT-tagged smolts on which to base analysis. Portions of the LCR Chinook and coho salmon ESUs have had sample groups PIT-tagged, but tagged smolts are not representative of all segments of these ESUs. Impacts of cormorants on these ESUs are summarized in Appendix A. Columbia River chum juveniles are not PIT-tagged but chum are largely absent from cormorant diets during the cormorant breeding season, so predation rates are presumably quite low (Lyons 2010).

Table 3. Generational time estimates for selected Columbia Basin salmon and steelhead populations listed under the U.S. Endangered Species Act (ESA).[1] Salmonid populations are broken down into evolutionarily significant units (ESU) for salmon and distinct population segments (DPS) for steelhead. Sources as noted.

Species	DPS/ESU	Generational Time (years)
Chinook	$SR_{S/S}$[1]	4.3
	SR_{F}[1]	3.7
	UCR_{Sp}[1]	4.3
	UWR_{Sp}[1]	4.4
Sockeye	SR[2]	3.0
Steelhead	SR[1]	5.8
	UCR[1]	3.8
	MCR[1]	4.8

[1]McClure et al. (2003)
[2]Torbeck et al. (2008)

Table 4. Percentage increases in the average annual population growth rate (λ) of selected salmon and steelhead ESUs for various levels of reduction in predation by double-crested cormorants from the East Sand Island colony. Estimates are provided for a range of assumptions regarding how much compensatory mortality may occur if cormorant predation is reduced.

		Chinook salmon				Sockeye salmon	Steelhead		
	Reduction in Predation	$SR_{S/S}$	SR_F	UCR_{Sp}	UWR_{Sp}	SR	SR	UCR	MCR
0% Compensation	25%	0.3%	0.2%	0.2%	0.1%	0.4%	0.5%	0.5%	0.5%
	50%	0.6%	0.4%	0.4%	0.2%	0.8%	0.9%	1.1%	1.1%
	75%	0.9%	0.7%	0.6%	0.3%	1.2%	1.4%	1.6%	1.6%
	100%	1.1%	0.9%	0.9%	0.4%	1.6%	1.8%	2.1%	2.1%
25% Compensation	25%	0.2%	0.2%	0.2%	0.1%	0.3%	0.4%	0.4%	0.4%
	50%	0.4%	0.3%	0.3%	0.2%	0.6%	0.7%	0.8%	0.8%
	75%	0.6%	0.5%	0.5%	0.2%	0.9%	1.0%	1.2%	1.2%
	100%	0.9%	0.7%	0.6%	0.3%	1.2%	1.4%	1.6%	1.6%
50% Compensation	25%	0.1%	0.1%	0.1%	0.1%	0.2%	0.2%	0.3%	0.3%
	50%	0.3%	0.2%	0.2%	0.1%	0.4%	0.5%	0.5%	0.5%
	75%	0.4%	0.3%	0.3%	0.2%	0.6%	0.7%	0.8%	0.8%
	100%	0.6%	0.4%	0.4%	0.2%	0.8%	0.9%	1.1%	1.1%
75% Compensation	25%	0.1%	0.1%	0.1%	<0.1%	0.1%	0.1%	0.1%	0.1%
	50%	0.1%	0.1%	0.1%	0.1%	0.2%	0.2%	0.3%	0.3%
	75%	0.2%	0.2%	0.2%	0.1%	0.3%	0.4%	0.4%	0.4%
	100%	0.3%	0.2%	0.2%	0.1%	0.4%	0.5%	0.5%	0.5%

Table 5. Hypothetical maximum cumulative potential benefit (expressed as percentage increases in the average annual population growth rate [λ]) to steelhead DPSs originating upstream of Bonneville Dam resulting from management to reduce predation by double-crested cormorants from the East Sand Island colony, assuming no other mortality factors compensate for reductions in cormorant predation. For comparison, potential benefits from management to reduce Caspian tern predation in the Columbia River estuary (calculated different ways in USFWS 2005 and USACE et al. 2007), for management under consideration to reduce avian predation in the Columbia Plateau region (Lyons et al. 2011a), and for the cumulative total of all recovery actions in the 2008 Federal Columbia River Power System Biological Opinion (BiOp; NOAA 2008) are presented below. Reductions in avian predation in the estuary have the potential to benefit a larger number of salmonid DPSs/ESUs not listed here than do proposed actions in the Columbia Plateau region.

Action	Steelhead DPS[6]			Number of Birds Managed (Individuals)	Cumulative Benefit to Upper Basin Steelhead per 10,000 Managed Birds[5]
	SR	UCR	MCR		
33% Reduction in Predation by East Sand Island Double-crested Cormorants	0.6%	0.7%	0.7%	8,400	2%
67% Reduction in Predation by East Sand Island Double-crested Cormorants	1.2%	1.4%	1.4%	16,800	2%
Complete Elimination of Predation by East Sand Island Double-crested Cormorants	1.8%	2.1%	2.1%	25,200	2%
Complete Elimination of Predation by five Columbia Plateau Waterbird Colonies[1]	1.0%	5.0%	-	9,100	7%
67% Reduction in Predation by East Sand Island Caspian Terns (CATE EIS)[2]	1.4%	2.6%	1.7%	13,750	4%
67% Reduction in Predation by East Sand Island Caspian Terns (2008 FCRPS BiOp)[3]	0.8%	0.8%	0.8%	13,750	2%
All Actions of 2008 FCRPS BiOp[4]	4%	18-24%	4%	(13,750)	-

[1]Based on PIT tag recovery rates during 2007 – 2010 including corrections for detection efficiency and deposition rate (Lyons et al. 2011a).
[2]Based on PIT tag recovery rates during 1999 – 2003 (USFWS 2005, Good et al. 2007) corrected for detection efficiency (unpublished data cited in Good et al. 2007) and deposition rate at East Sand Island (Collis et al. 2007), and presuming a colony size reduction to 3,125 pairs from ca. 10,000 pairs.
[3]Based on bioenergetics-based predation rates at the species level during 2003 – 2006 (USACE et al. 2007).
[4]From NOAA (2008). Ranges represent differing assumptions used to calculate λ values. Includes Caspian tern management in the Columbia River estuary.
[5] Cumulative benefits to upper basin steelhead DPSs are based on the sum of the delta lambdas divided by the number of birds managed.
[6]DPS = distinct population segment; SR = Snake River; UCR = Upper Columbia River; MCR = Middle Columbia River

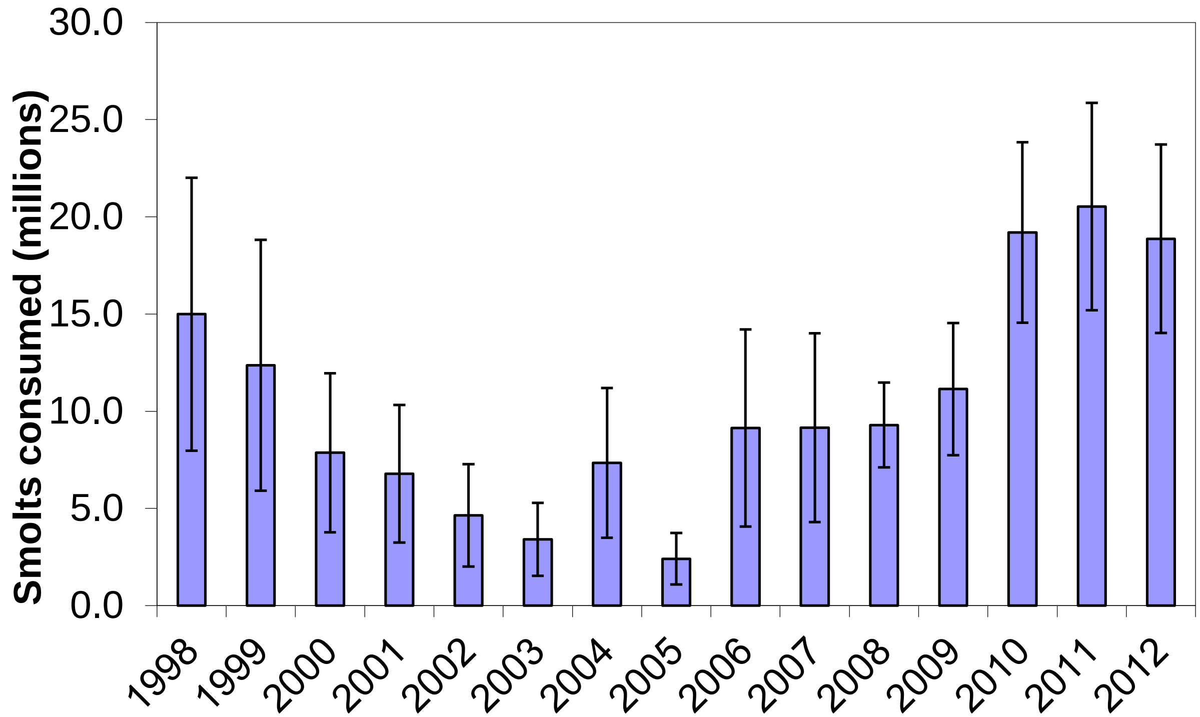

Figure 1. Bioenergetics-based estimates of annual smolt consumption (best estimate and 95% confidence interval) by double-crested cormorants nesting in the Columbia River estuary (Lyons 2010, BRNW 2013).

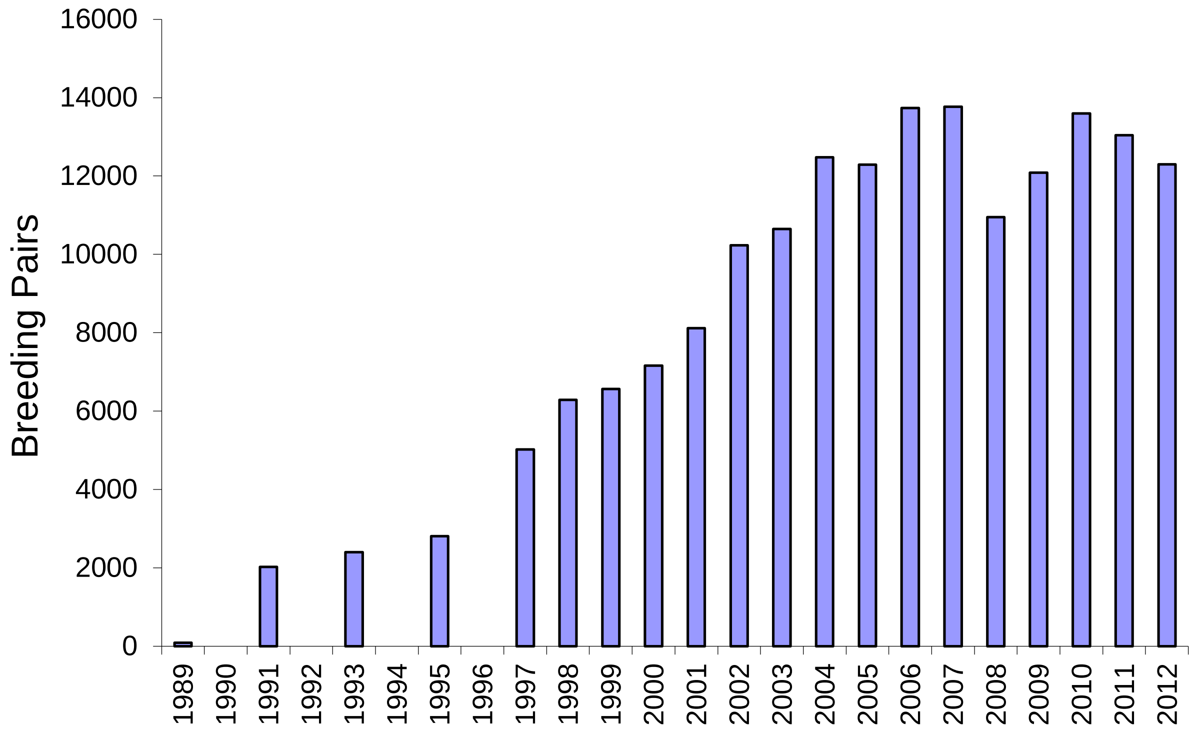

Figure 2. Size of the double-crested cormorant breeding colony on East Sand Island in the Columbia River estuary since island colonization in 1989 (data from Carter et al. 1995, Anderson et al. 2004a, Naughton et al. 2007, Adkins and Roby 2010, BRNW 2013). No data are available for 1990, 1992, 1994, and 1996. Average colony size during 2007 – 2012 was 12,600 breeding pairs.

APPENDIX A

ASSESSMENT OF POTENTIAL BENEFITS TO ESA-LISTED LOWER COLUMBIA RIVER CHINOOK AND COHO SALMON POPULATIONS

In addition to the salmon and steelhead populations listed under the U.S. Endangered Species Act (ESA) that are discussed in the main text of this report (those originating wholly upstream of Bonneville Dam and spring-run Chinook salmon originating from the Upper Willamette River [UWR]), there are ESA-listed salmonid populations from the Lower Columbia River (LCR) that might also benefit if predation on salmonid smolts by double-crested cormorants nesting on East Sand Island were reduced. For example, some of the limited data available for LCR Chinook and coho salmon suggest that impacts from cormorant predation on these fish may be significant (Sebring et al. 2013) and perhaps greater than cormorant impacts on upriver or inland salmonid populations. In this appendix we evaluate the potential benefits to LCR Chinook and coho salmon evolutionarily significant units (ESUs) associated with possible reductions in cormorant predation in the Columbia River estuary. Other distinct population segments (DPSs) from the lower river basin (i.e., LCR and UWR steelhead) may also benefit significantly from reductions in cormorant predation; however, data are not available to assess cormorant predation on these particular DPSs. Lower Columbia River chum salmon are largely absent from cormorant diets during the cormorant breeding season, so reductions in cormorant predation are unlikely to benefit that ESU.

For LCR Chinook and coho salmon, an evaluation of the potential impact of predation by East Sand Island cormorants is challenging due to limited data. The available data for these

ESUs during the 2007-2010 outmigration years were pooled in order to estimate predation rates and potential ESU-specific benefits associated with cormorant management in the Columbia River estuary. LCR Chinook and coho data were limited relative to upriver DPSs/ESUs because of small numbers of PIT-tagged smolts, plus sample groups were less representative of the entirety of each ESU and tagging effort was less consistent and often smaller in some years. Thus, LCR Chinook and coho data do not capture a comparable range of within-ESU or inter-annual variability in the impact of cormorant predation. Furthermore, due to a lack of in-river PIT tag interrogation sites in the lower mainstem river, post-release interrogations were not available for fish released downstream of Bonneville Dam. Consequently, conclusions drawn here are less robust than those for upriver DPSs/ESUs. Recognizing these limitations, the analyses below incorporate the best available data, and offer a preliminary comparison between potential benefits from cormorant management for DPSs/ESUs from the lower and upper basins of the Columbia River.

Finally, some additional information is important to consider when reviewing the results presented in this appendix. Following the 2001 *Alsea Valley Alliance v. Evans* legal decision, a majority of hatchery-reared Chinook and coho salmon smolts produced and released in the LCR region were recognized to be a part of the ESA-listed LCR Chinook and coho ESUs (listing status for both ESUs = threatened; USOFR 2005). These hatchery-reared smolts make up a majority of the annual juvenile production for each ESU. The primary purpose of this hatchery production is to facilitate harvest opportunities and consequently all hatchery-reared smolts are adipose fin-clipped and excluded from 4(d) protection under the ESA (USOFR 2005, NMFS 2012). Predation rates by East Sand Island cormorants on the hatchery-reared components of each of these LCR ESUs are quite high and often greater than on the wild components of the

ESUs, as well as greater than predation rates for upper basin DPSs/ESUs. In this appendix, we provide cormorant predation rates for each distinct ESU component for which data are available, including these hatchery-reared groups. However, consistent with our approach for upper-basin salmonids, we estimate potential benefits of reductions in predation by cormorants (the potential improvement in the average annual population growth rate, i.e. $\Delta\lambda$) for the entire LCR ESUs (i.e., wild and hatchery-reared fish combined).

Predation Rate Estimation

The same general methods used to estimate predation rates for upper-basin salmonid populations (see main text) were used for Lower Columbia River Chinook and coho salmon, with the aforementioned data limitations from small sample sizes, lack of representative tagging, and lack of post-release interrogations at mainstem dams.

Lower Columbia River Chinook Salmon ESU: The LCR Chinook salmon ESU includes substantial diversity in life history traits, geographic origin, and rearing history (NMFS 2012). Adults exhibit three types of run-timing: spring, fall ("tule" stock), and late-fall ("brights"). Spring Chinook juveniles generally exhibit a "stream-type" life history, arriving in the estuary primarily as yearlings and quickly exiting to the ocean, whereas fall and late-fall Chinook typically exhibit an "ocean-type" life history, arriving in the estuary as sub-yearlings and residing in the estuary for longer periods (several weeks or months). Geographically, LCR fall Chinook are typically divided among three population strata: Coast, Cascade (both downstream of Bonneville Dam), and Gorge (both downstream and upstream of Bonneville Dam). LCR spring Chinook are divided into two population strata: Cascade and Gorge. Hatchery production makes a substantial contribution to both the spring and fall stocks. Overall, a majority of LCR Chinook smolts are reared in hatcheries (Ferguson 2007, 2008, 2009, 2010).

For the purposes of assessing predation rates by East Sand Island cormorants on LCR Chinook, we partitioned the ESU into components based on juvenile age class (yearling [= "spring"] or sub-yearling [= "fall", representing both tule and bright stocks]), geographic origin (upstream or downstream of Bonneville Dam), and rearing-type (wild or hatchery-reared). Using this organization, there were eight distinct components of the LCR Chinook ESU. A sufficient sample size of PIT-tagged smolts (n ≥ 100 "available" smolts per year; see below) was obtained in five of the eight component parts of the overall ESU. In all cases, the groups of smolts PIT-tagged were an opportunistic sample of the ESU component.

For the LCR Chinook ESU components, the number of smolts "available" to East Sand Island cormorants was taken to be the number of smolts tagged and released within the geographic boundary of the ESU, as defined by NOAA (NMFS 2012). Using these estimates of smolt availability and the number of tags subsequently recovered at the East Sand Island cormorant colony (corrected for detection efficiency and deposition rate as described in the main text), we were able to estimate predation rates for five of the eight ESU components (Table A1). There was substantial variation in predation rates between ESU components and, as seen with DPSs/ESUs originating upstream of Bonneville Dam, large inter-annual variability as well.

For the three ESU components where data were lacking (hatchery-reared and wild spring Chinook produced downstream of Bonneville Dam and wild fall Chinook produced upstream of Bonneville Dam), we used two alternative assumptions to calculate the overall ESU-level predation rate: (1) the predation rate for these components was 0%, or (2) the predation rate was equal to that for the most susceptible component identified (43% for hatchery-reared fall

Chinook produced downstream of Bonneville Dam). These assumptions were both viewed as biologically unlikely but useful to determine the probable upper and lower boundaries of uncertainty for the overall ESU-level predation rate.

To calculate the overall ESU-level predation rate, we used the estimated or assumed predation rates for each component group (Table A1), and calculated a weighted average, weighting according to the relative availability (portion of the ESU as a whole) of each component group. Each group's relative availability was derived from estimates of smolt production provided by John Ferguson and colleagues at NOAA's Northwest Fisheries Science Center (Ferguson 2007, 2008, 2009, 2010; Table A1). The ESU-level predation rate was 24%, assuming the predation rate was 0% for groups where data were lacking, and 28% assuming those predation rates were equal to that for hatchery-reared fall Chinook released downstream of Bonneville Dam (43%). To estimate the potential improvement in the LCR Chinook ESU average annual population growth rate for various reductions in cormorant predation (see below), we used a predation rate value of 26%, equal to the mean of the results for the two alternative assumptions. Those alternative scenarios represented the unlikely extreme possibilities, so an intermediate value seemed reasonable.

Lower Columbia River Coho Salmon ESU: The LCR coho salmon ESU also includes smolts of differing geographic origin (upstream and downstream of Bonneville Dam) and rearing history (wild and hatchery-reared; NMFS 2012). The overwhelming majority of smolts in this ESU are hatchery-reared and released downstream of Bonneville Dam; however, components of the ESU result from wild production both upstream and downstream of Bonneville Dam (Ferguson 2007, 2008, 2009, 2010). As was done for LCR Chinook, we estimated cormorant predation rates on each of the individual components that make up the entire LCR coho ESU.

Data were available from PIT-tagged smolts ($n \geq 100$ "available" smolts per year; see above) for two of the three component parts of the overall ESU (wild and hatchery-reared smolts originating downstream of Bonneville Dam). As with other LCR ESUs, the groups of smolts PIT-tagged were an opportunistic sample of the ESU component, and data from all four study years (2007-2010) within a group were not always available. And similar to LCR Chinook, substantial inter-group and inter-annual variability in predation rates was seen. To estimate an overall ESU-level predation rate, we assumed that the predation rate on wild smolts originating upstream of Bonneville Dam was equal to that on wild smolts originating downstream of Bonneville Dam (10%), and combined the component ESU predation rates weighting by availability as with the LCR Chinook ESU (Table A2). The component of the LCR coho ESU that consisted of wild smolts originating upstream of Bonneville Dam was so small (< 1% of the total ESU; Ferguson 2007, 2008, 2009, 2010) that the predation rate assumption for this component group had a negligible effect on the ESU-level predation rate. The resulting LCR coho ESU-level predation rate was 28%, similar to the 26% predation rate on LCR Chinook.

Potential Benefits

We calculated changes in the population trajectory, or average annual population growth rate ($\Delta\lambda$), for the same levels of reduction in cormorant predation rate on smolts and range of compensatory response in smolt mortality as for the DPSs/ESUs discussed in the main text. The generational time for LCR Chinook (3.7 years) was taken from McClure et al. (2003; Table 5). For LCR coho, the generational time was not known; we used a value of 3.0 years, which assumes a negligible contribution of jacks to the breeding population.

Potential increases in λ for complete elimination of predation by East Sand Island double-crested cormorants, and assuming no other mortality factors compensated for this reduction in mortality due to cormorant predation (i.e., mortality from cormorant predation is fully additive), were 8.9% for LCR Chinook and 11.4% for LCR coho salmon. These estimates represent the maximum possible benefit; benefits for a range of reductions in cormorant predation and levels of compensation are presented in Table A3.

Potential benefits for these LCR ESUs were greater than those for DPSs/ESUs originating higher in the basin, given the same reduction in cormorant predation and level of compensatory mortality. For example, the benefits projected for upper basin DPSs/ESUs, given complete elimination of cormorant predation and no compensation, were 0.6 – 1.2% for Chinook salmon ESUs, 1.6% for the Snake River sockeye salmon ESU, and 1.9 – 2.5% for steelhead DPSs. The level of compensatory mortality that may occur for reductions in cormorant predation is unknown; however, it is reasonable to expect that LCR ESUs may experience more compensatory mortality than those from higher in the basin. Upper basin smolts have experienced many of the rigors of out-migration by the time they reach the estuary, whereas LCR smolts have been exposed to relatively few mortality factors. Particularly for the hatchery-reared component of the LCR ESUs that are released directly into the estuary, it is reasonable to assume that individuals of low-fitness (due to disease, lack of smoltification, or other factors) have not yet been culled from the population, whereas for upper basin ESUs those individuals more susceptible to a broad range of mortality factors have likely already been culled prior to arrival in the estuary. For this reason, direct quantitative comparison of potential benefits between LCR ESUs and upriver ESUs/DPSs for a given level of reduction in cormorant predation, assuming the same level of compensation, is problematic.

In summary, predation rates on LCR Chinook and coho salmon by East Sand Island cormorants appear to be greater than for upriver ESUs/DPSs that are ESA-listed, although additional studies specifically designed to measure these predation rates would substantially strengthen this conclusion. Based on the data available, potential benefits to LCR ESUs would also be greater than for upriver ESUs/DPSs, for comparable reductions in cormorant predation, although greater compensation for reductions in predation might be expected for these lower river ESUs than for ESUs/DPSs originating higher in the basin. Given the data limitations for LCR ESUs, quantifying management objectives for reductions in cormorant predation based on potential benefits to upper basin ESUs/DPSs would be a more rigorous approach than to quantify objectives based on the potential benefits for LCR ESUs, which currently cannot be estimated with the same precision as upriver DPSs/ESUs. It is apparent, however, that any reductions in cormorant predation put in place to benefit upper basin ESUs/DPSs would also substantially benefit the LCR Chinook and coho salmon ESUs, potentially to an even greater extent.

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Table A1. Estimated availability of components of the Lower Columbia River Chinook salmon ESU and associated predation rates by East Sand Island double-crested cormorants. Predation rates are averages of annual values during 2007 – 2010 and include corrections for PIT tag detection efficiency and deposition rate. The overall ESU-level predation rate was estimated to be 26% (see text for details).

Run	Rearing Type	Origin (above/below Bonneville Dam)	Portion of ESU[1]	Number of years with data ($n \geq 100$)	Sample Size (available per year)	Predation Rate
Spring	Hatchery	Below	5%	0	NA	NA
	Wild	Below	3%	0	NA	NA
	Hatchery	Above	3%	4	22,455 – 37,404	4%
	Wild	Above	0.1%	2	112 – 308	5%
Fall	Hatchery	Below	38%	4	11,430 – 21,347	43%
	Wild	Below	22%	1	469	12%
	Hatchery	Above	27%	3	38,963 – 39,884	18%
	Wild	Above	2%	0	NA	NA

[1]Derived from Ferguson (2007, 2008, 2009, 2010).

Table A2. Estimated availability of components of the Lower Columbia River coho salmon ESU and associated predation rates by East Sand Island double-crested cormorants. Predation rates are averages of annual values during 2007 – 2010 and include corrections for PIT tag detection efficiency and deposition rate. The overall ESU-level predation rate was estimated to be 28% (see text for details).

Rearing Type	Origin (above/below Bonneville Dam)	Portion of ESU[1]	Number of years with data ($n \geq 100$)	Sample Size (available per year)	Predation Rate
Hatchery	Below	91%	4	1,010 – 8,829	30%
Wild	Below	8%	3	1,010 – 1,020	10%
Hatchery	Above	NA	NA	NA	NA
Wild	Above	0.7%	0	NA	NA

[1]Derived from Ferguson (2007, 2008, 2009, 2010).

Table A3. Percentage increases in the average annual population growth rate (λ) of selected Lower Columbia River Chinook and coho ESUs for various levels of reduction in predation by double-crested cormorants from the East Sand Island colony. Estimates are provided for a range of assumptions regarding how much compensatory mortality may occur if cormorant predation is reduced.

	Reduction in Predation	LCR Chinook	LCR Coho
0% Compensation	25%	2.2%	3.1%
	50%	4.4%	6.1%
	75%	6.3%	8.9%
	100%	8.2%	11.5%
25% Compensation	25%	1.7%	2.4%
	50%	3.3%	4.6%
	75%	4.9%	6.8%
	100%	6.3%	8.9%
50% Compensation	25%	1.1%	1.6%
	50%	2.2%	3.1%
	75%	3.3%	4.6%
	100%	4.4%	6.1%
75% Compensation	25%	0.6%	0.8%
	50%	1.1%	1.6%
	75%	1.7%	2.4%
	100%	2.2%	3.1%

APPENDIX B

RECENT NESTING OF DOUBLE-CRESTED CORMORANTS ELSEWHERE IN THE COLUMBIA RIVER ESTUARY

In addition to nesting at East Sand Island, double-crested cormorants have nested at a variety of locations within the Columbia River estuary over the last three decades, including Trestle Bay, a pile dike near the town of Chinook, WA, pilings at Desdemona Sands, the Astoria-Megler Bridge, Rice Island, Miller Sands Spit, channel markers near Miller Sands Spit, and channel markers near Woody and Fitzpatrick islands (Carter et al. 1995, Adkins and Roby 2010). Since 2000, we have opportunistically surveyed for cormorant nesting activity throughout the estuary. During 2009 – 2012, double-crested cormorants nested only at East Sand Island, the Astoria-Megler Bridge, and the upper estuary channel markers near Miller Sands Spit, Woody Island, and Fitzpatrick Island (BRNW 2013). Breeding numbers appear to have been stable at the upper estuary channel markers since at least 2003, but the Astoria-Megler Bridge site was initially colonized by double-crested cormorants in 2004 (pelagic cormorants have nested on the bridge since at least 2000) and numbers have increased since the initial colonization (Table D1). The average number of breeding pairs at these sites during 2009 – 2012 was 342 pairs, ranging from a minimum of 259 in 2009 to a maximum of 482 in 2012. The 482 pairs in 2012 represents the greatest number of cormorants documented to be breeding in the estuary away from East Sand Island since 1998, although survey coverage was not complete in all years.

A few data are available to assess the predation impacts on salmonids from cormorants nesting elsewhere in the estuary other than East Sand Island. A 1997 – 1998 study compared the diet composition of cormorants nesting at East Sand Island (rkm 8) to those nesting at Rice Island (rkm 34) and the nearby channel markers. During that study, salmonids made up 46% of the Rice Island/channel marker cormorant diet (by biomass) and 16% of the East Sand Island cormorant diet (Collis et al. 2002). During 2005 – 2008, cormorants nested at Miller Sands Spit and in 2006 and 2007 recovery of PIT tags was performed on-colony following the breeding season. In 2006, a small colony also existed at Rice Island and PIT tag recovery was also performed there in that year. Per capita PIT tag recovery rates (corrected for detection efficiency) at these two sites ranged from 1.4 to 8.5 times greater than at East Sand Island for the same periods (BRNW 2007, 2008). These limited data are not adequate to allow estimation of predation rates for these upper estuary sites, but a consistent pattern of greater reliance on salmonids by cormorants nesting in the upper estuary is evident. No diet composition or PIT tag recovery data exists for the Astoria-Megler Bridge colony (approximately midway between East Sand Island and these upper estuary locations), so it is not possible to confirm the logical prediction that impacts to salmonids by cormorants nesting there would be intermediate between those nesting at East Sand Island and those nesting in the upper estuary.

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Table D1. Number of breeding pairs of double-crested cormorants nesting on the Astoria-Megler Bridge and channel markers in the upper estuary near Miller Sands Spit, Woody Island, and Fitzpatrick Island.

Year	Astoria-Megler Bridge	Upper Estuary Channel Markers[1]
2003	0	183
2004	6	194
2005	14	208
2006	7	152
2007	8	155
2008	20	174
2009	24	235
2010	63	254
2011	62	248
2012	139	343

[1]Surveys of channel markers included only eight markers near Miller Sands Spit prior to 2009. An additional four markers near Woody and Fitzpatrick islands were included in the surveys beginning in 2009.