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

DRAFT 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 anadromous salmonid populations from the Columbia River basin that are listed under the U.S. Endangered Species Act. We examined the potential benefits of reductions in predation by double-crested cormorants 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 primarily originating from above Bonneville Dam (rkm 235). The East Sand Island double-crested cormorant colony, ca. 12,600 pairs during 2007 – 2010, is the largest colony for this species in western North America, and cormorants from this colony have been documented to consume millions of smolts per year.

Using predation rate data based on recoveries of smolt passive integrated transponder (PIT) tags on the East Sand Island colony and 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 DPS/ESU. Estimates were produced for a range of reductions in cormorant predation and for a range in levels of compensatory mortality for smolts.

Potential increases in λ (Δλ) for complete elimination of predation by East Sand Island double-crested cormorants, assuming no other mortality factors would compensate for this reduction in predation, ranged from 0.6 – 1.2% for Chinook salmon ESUs originating above

Bonneville Dam, was 1.6% for the Snake River sockeye salmon ESU, and ranged from 1.9 – 2.5% for steelhead DPSs originating above Bonneville Dam. If a moderate level of compensatory smolt mortality (e.g., 50%) occurred in response to a complete elimination of cormorant predation, Δλ values would drop below 1% for Chinook and sockeye salmon ESUs, but remain 1% or greater 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 above 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 Caspian tern management in terms of benefits per managed bird due to the lower per capita impacts of cormorants on survival of salmonids originating from above 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 we analyzed, 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 (1) the degree to which other smolt mortality factors may compensate for reductions in mortality from cormorant predation, (2) the off-colony deposition rate of PIT tags from PIT-tagged salmonids consumed by cormorants, and (3) the impacts of cormorant predation on survival of ESA-listed salmonids from populations originating primarily below Bonneville Dam.

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 predators on juvenile salmonids across the basin (e.g., Collis et al. 2002, Evans et al. 2011). 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 waterbird 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).

At East Sand Island in the Columbia River estuary, in addition to the large Caspian tern colony, there also exists 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 recent years (Carter et al. 1995, Anderson et al. 2004a,Adkins and Roby 2010), 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 40% of all double-crested cormorants in western North America (Adkins and Roby 2010). Double-crested cormorants are strictly piscivorous and in the estuary juvenile salmonids have been shown to be 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, Appendix B).

A variety of approaches have been used to assess the impacts of avian predators on smolts 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 at bird colonies (Collis et al. 2001, Ryan et al. 2003, Maranto et al. 2010, Evans et al. 2011), and 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, salmonid population-level demographic benefits, 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 estuary cormorants on survival of Columbia River juvenile salmonids 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 into the context of other recovery actions for Columbia River 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 if 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, making it difficult to predict impacts in any given year, regardless of colony size (Appendix B, Figure B1). 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.

The estimated benefits to salmonid populations presented here are applicable regardless of what type of management action achieves reductions in cormorant predation and mortality of juvenile salmonids.

These analyses focus on potential benefits to ESA-listed anadromous salmonid populations, and in particular those that originate above Bonneville Dam (river km 235) and pass through at least one dam in the FCRPS. Cormorants also prey upon anadromous salmonids belonging to populations of cultural and economic concern that are not ESA-listed, 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 – 2010 was 12,600 pairs (Adkins and Roby 2010; Figure 1).

Analysis Framework

The process we used to estimate benefits that might accrue to salmonid populations from reductions in predation by double-crested cormorants from 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):

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

where S_i is the initial survival rate, S_f is the final survival rate following a recovery action, G is the average generational time, and $\Delta\lambda$ is the percentage change in the average annual population growth rate. This 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). 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 below 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 two ways: either (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 waterbird 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. 2011). Relying upon predation rates for a sample of smolts does not require estimation of either smolt availability or 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 below Bonneville Dam and are similarly not PIT-tagged. A minority of LCR steelhead are produced above 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 Lower Columbia River 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 below Bonneville Dam (e.g., Sebring et al. 2010a, 2010b). These ESA-listed, 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 LCR smolts naturally-spawned or the minority portion of these ESUs that are produced above Bonneville Dam.

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, below 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 above Bonneville Dam was defined as those PIT-tagged smolts known to pass below 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 below 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 below 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 vs. 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).Substantial differences 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 above 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– 2010, 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 above that point, and 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 East Sand Island later in the season (June and July) do not extend as far into the upper estuary, with observed activity confined to below rkm 60 (Anderson et al. 2004b). Survival of smolts tagged with acoustic transmitters and released below 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 into 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 for Caspian terns nesting on 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 S. Sebring using the methods of Ryan et al. (2003), after nesting cormorants had dispersed following each breeding season (August to November). 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. Corrections for less than 100% detection efficiency of deposited PIT tags were made using the sown control tag method of Evans et al. (2011).

Annual PIT tag recovery rates (number present at the cormorant colony after correcting for detection efficiency divided by the number available at that life history stage as defined above) were averaged over the years 2007 – 2010 to obtain the current PIT tag recovery rate.

Converting PIT tag recovery rates into predation rates: Colony-based PIT tag recovery rates are an excellent indication of the relative impacts of avian predation on the various salmonid DPSs/ESUs, particularly when comparing the impacts of birds at a single breeding colony on the various DPSs/ESUs that birds from that colony prey upon. Colony-based PIT tag recovery rates do not directly account for all PIT-tagged fish consumed by birds nesting at that colony, however, as adult birds may deposit 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 convert on-colony PIT tag recovery rates into unbiased estimates of predation rates, an “off-colony” PIT tag deposition rate, or the proportion of ingested PIT tags that were deposited away from the colony and/or damaged during ingestion or egestion processes, is required.

PIT tag deposition rates have been systematically 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 2011 a pilot study was initiated at the East Sand Island cormorant colony to identify techniques that might allow such an effort. A necessary component of such a study involves identifying fish PIT-tagged with known tag codes that are positively determined to be consumed by breeding cormorants. The degree to which these known PIT tags are detected during subsequent PIT tag recovery efforts can then be used to estimate the off-colony deposition rate (after correcting for PIT tag detection efficiency). In 2011 at East Sand Island, PIT-tagged fish were thrown from the open window of 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 by nesting adult cormorants. This provided an inventory of PIT-tagged fish that were known to have been consumed by East Sand Island cormorants. From May 26th to June 11th, cormorants consumed a total of 88 PIT-tagged fish. Within this period of experimentation, at least 12 PIT-tagged fish were consumed per day on 6 different days.

This pilot deposition rate study is properly viewed as an initial investigation into off-colony deposition rates by cormorants nesting at East Sand Island. An important uncertainty in the study design was whether PIT tags in fish consumed by cormorants at the colony are deposited away from the colony at a similar rate as those PIT tags in fish consumed away from the colony at a foraging site. Results for Caspian terns indicated that PIT tag deposition rate was relatively similar regardless of whether the PIT-tagged fish was consumed at the colony or foraging sites away from the colony (Collis et al. 2007). An initial attempt was undertaken in 2011 to explore this uncertainty for cormorants nesting at East Sand Island; nesting cormorants were offered PIT-tagged fish in the morning and in the early evening in order to compare the resulting off-colony deposition rates during periods when cormorant behavior may be different. There was no significant difference between off-colony deposition rates of fish consumed in the morning and in the evening. This initial result, while not conclusive, does at least suggest that time of day does not have a large effect on cormorant off-colony deposition rates.

Predation rates can be estimated without bias by dividing the PIT tag recovery rate by one minus the off-colony PIT tag deposition rate. We proceeded with the analysis using the estimate of off-colony deposition rate from the 2011 pilot study, as it provides the only available information on this parameter for cormorants. Daily off-colony PIT tag deposition rates ranged from 33 – 79%, with a mean of daily values equal to 59% (N = 6). This corresponds to 59% of all PIT tags consumed by East Sand Island cormorants being either deposited somewhere other than on the colony or damaged during the ingestion/egestion process. This compares to a 37% off-colony deposition rate for Caspian terns nesting at Crescent Island on the mid-Columbia

River (Collis et al. 2007). PIT tag recovery rates, after correction for detection efficiency, were further corrected for this off-colony PIT tag deposition by multiplying by 2.44 (1/ (1-0.59)) to estimate unbiased predation rates.

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. 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, skin disease, and other factors, were significantly more susceptible to avian predation than apparently healthy smolts (Hostetter et al. 2011). 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. (2011) 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.

Another line of evidence 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 below Bonneville Dam, and (2) below Astoria, Oregon (rkm 10) at night and on an outgoing tide (Marsh et al. 2011). For the releases just below 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).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. 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; Table 5), 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 recovery rates in Evans et al. [2011]) 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).

RESULTS

Estimates for cormorant predation rates on salmon and steelhead DPSs/ESUs during 2007 – 2010 ranged from 2.7% for Upper Willamette River spring-run Chinook to 13% for Snake River steelhead (Table 1). Predation rates were greatest for the three steelhead DPSs examined, consistent with predation rates by Caspian terns throughout the Columbia River basin (Collis et al. 2001, Lyons 2010, Evans et al. 2011). Cormorant predation rates on Snake River sockeye (4.8%) fell within the range seen for the various Chinook ESUs (2.7 – 5.1%).

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 0.6 – 1.2% for Chinook salmon ESUs, was 1.6% for the Snake River sockeye salmon ESU, and ranged from 1.9 – 2.5% for steelhead DPSs (Table 2). These estimates represent the theoretical maximum possible benefits for salmonid populations if management is maximized and mortality from cormorant predation is fully additive. If a moderate level of compensation (e.g., 50%) occurred for this complete elimination of cormorant predation, $\Delta\lambda$ values would drop below 1% for Chinook salmon and sockeye salmon ESUs, but remain 1% or greater for steelhead DPSs. If the reduction in cormorant predation was intermediate (50%) and mortality due to cormorant predation was considered fully additive, $\Delta\lambda$ values would again drop below 1% for Chinook salmon and sockeye salmon ESUs, but remain 1% or greater for steelhead DPSs. Regardless of assumptions regarding potential compensation and the degree of cormorant management that might occur, benefits were lower for DPSs/ESUs from the Upper Columbia River than those from other areas above Bonneville Dam.

Benefits to salmonid populations ($\Delta\lambda$ values) from reductions in predation by 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 4.6% for the three upper basin steelhead DPSs (see Table 3). 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 3]). The maximum potential benefits from management to reduce predation by cormorants nesting on East Sand Island for all of the individual salmonid DPSs/ESUs considered here (range = 0.6 – 2.5%, 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) on the Columbia Plateau ($\Delta\lambda = 5.0\%$; Lyons et al. 2011a).

DISCUSSION

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):

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

For example, if $\lambda_{old} = 0.93$ and $\Delta\lambda = 3.30\%$, then

$$\lambda_{new} = 0.93 \times \left(1 + \frac{3.30}{100}\right) = 0.93 \times 1.033 = 0.9607.$$

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 3). 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 were based on bioenergetics-based, species-level estimates of predation rates (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 on the Columbia Plateau. 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 by the five colonies of piscivorous waterbirds on the Columbia Plateau. 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 on the Columbia Plateau for Upper Columbia River steelhead, 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 and Upper Columbia river basins, while management to reduce predation by cormorants nesting at the East Sand Island colony would benefit all 8 of the ESA-listed DPSs/ESUs considered here as well as potentially benefitting several of the ESA-listed DPSs/ESUs produced primarily below Bonneville Dam (e.g., Appendix A). A two-thirds reduction in predation by the East Sand Island cormorant colony would likely produce a very similar level of benefit for salmonid populations originating above 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 3).

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 3). Benefits from cormorant management at East Sand Island are very comparable, however, to most individual recovery actions included in the BiOp (NOAA 2008).

Management to reduce predation on juvenile salmonids originating above Bonneville Dam by double-crested cormorants from the East Sand Island colony would not be as efficient as management focused primarily on Caspian terns in order to achieve a comparable benefit per managed bird (Table 3; 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, a greater number of cormorants must be managed (see Table 3). Despite the larger body size of double-crested cormorants and correspondingly greater food requirements compared to Caspian terns, per capita predation rates on smolts originating above 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 on the Columbia Plateau (Evans et al. 2011). 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 two critical uncertainties where data were lacking. Perhaps the most critical uncertainty for assessing potential benefits to salmonid populations from reduced cormorant predation on juveniles is to what degree other mortality factors later in the life history might compensate for those reductions in mortality due to 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 adult returns (e.g., NOAA 2008). Numerous parties within the basin have pointed out 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, however (e.g., Russ Kiefer, Idaho Fish and Game, pers. comm.).

Two lines of inquiry ongoing within the basin are poised to make greater contributions on this issue relatively soon. First, further analysis and interpretation of the alternative barge study (Marsh et al. 2011) specifically with respect to this question of compensation will be informative. Second, efforts to analyze the relationship between smolt survival and avian predation rates during portions of the juvenile outmigration and, if possible, ocean residency, for groups of PIT-tagged smolts that experienced differential levels of avian predation will also soon better inform the additive/compensatory question(A. Evans and N. Hostetter, unpubl. data).

Another uncertainty critical to accurately estimating predation rates by double-crested cormorants nesting at East Sand Island is the off-colony deposition rate of PIT tags by cormorants. A portion of PIT tags in fish that are consumed by cormorants are excreted away from the colony or potentially damaged and not detected during colony-based PIT tag recovery efforts. We used the results from a pilot study conducted during a limited portion of just the 2011 breeding season and at just one location within the large East Sand Island cormorant colony. Comparable efforts to measure off-colony deposition rates of Caspian terns involved two methodologies, three years of data collection, and were conducted at two different tern colonies (Collis et al. 2007). The robustness of our results here would benefit significantly from additional measurements of this critical parameter for cormorants.

Despite these uncertainties, 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 contribute benefits to 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, *Entosphenus tridentatus*).

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REFERENCES

Adkins, J.Y., and D.D. Roby. 2010. A status assessment of the double-crested cormorant (*Phalacrocorax auritus*) in western North America: 1998 – 2009. U.S. Army Corps of Engineers, Portland, OR. Available on-line at www.birdresearchnw.org.

Anderson, C.D., D.D. Roby, and K. Collis. 2004a. Conservation implications of the large colony of double-crested cormorants on East Sand Island, Columbia River estuary, Oregon, U.S.A. Waterbirds 27: 155-160.

Anderson, C.D., D.D. Roby, and K. Collis. 2004b. Foraging patterns of male and female double-crested cormorants nesting in the Columbia River estuary. Canadian Journal of Zoology 82:541-554.

Antolos, M., D.D. Roby, D.E. Lyons, K. Collis, A.F. Evans, M. Hawbecker, and B.A. Ryan. 2005. Caspian tern predation on juvenile salmonids in the mid-Columbia River. Transactions of the American Fisheries Society 134:466-480.

Carter, H.R., A.L. Sowls, M.S. Rodway, U.W. Wilson, R.W. Lowe, G.J. McChesney, F. Gress, and D.W. Anderson. 1995. Population size, trends, and conservation problems of the Double-crested Cormorant on the Pacific Coast of North America. Colonial Waterbirds 18 (Special Publication 1): 189-215.

Collis, K., S. Adamany, D.D. Roby, D.P. Craig, and D.E. Lyons. 2000. Avian predation on juvenile salmonids in the Lower Columbia River: 1998 annual report. Bird Research Northwest. Available on-line at www.birdresearchnw.org.

Collis, K., D.D. Roby, D.P. Craig, B.A. Ryan, and R.D. Ledgerwood. 2001. Colonial waterbird predation on juvenile salmonids tagged with passive integrated transponders in the

Columbia River estuary: vulnerability of different salmonid species, stocks, and rearing types. Transactions of the American Fisheries Society 130:385-396.

Collis, K., D.D. Roby, D.P. Craig, S. Adamany, J.Y. Adkins, and D.E. Lyons. 2002. Colony size and diet composition of piscivorous waterbirds on the lower Columbia River: implications for losses of juvenile salmonids to avian predation. Transactions of the American Fisheries Society 131:537-550.

Collis, K. D.D. Roby, D.E. Lyons, Y. Suzuki, J.Y. Adkins, L. Reinalda, C. Hand, N. Hostetter, A.F. Evans, and M. Hawbecker. 2007. Research, monitoring, and evaluation of avian predation on salmonid smolts in the lower and mid-Columbia River: 2006 final season summary. Bird Research Northwest. Available on-line at www.birdresearchnw.org.

Evans, A.F.,N.J. Hostetter, K. Collis, D.D. Roby, D.E. Lyons, B.P. Sandford, R.D. Ledgerwood, and S. Sebring. 2011. A system-wide evaluation of avian predation on salmonid smolts in the Columbia River basin based on recoveries of passive integrated transponder (PIT) tags. Pages 81-178*in* Roby, D.D. (ed.). Impacts of avian predation on salmonid smolts from the Columbia and Snake rivers: A synthesis report to the U.S. Army Corps of Engineers, Walla Walla District. Bird Research Northwest. Available on-line at www.birdresearchnw.org.

Good, T.P., M.M. McClure, B.P. Sandford, K.A. Barnas, D.M. Marsh, B.A. Ryan, and E. Casillas. 2007. Quantifying the effect of Caspian tern predation on threatened and endangered Pacific salmon in the Columbia River estuary. Endangered Species Research 3: 11-21.

Hostetter, N.J., A.F. Evans, K. Collis, and D.D. Roby. 2011. Biotic and abiotic factors influencing susceptibility of juvenile steelhead to predation by Caspian terns and double-crested cormorants nesting on the Columbia Plateau. Pages 147-178*in* Roby, D.D. (ed.). Impacts of avian predation on salmonid smolts from the Columbia and Snake rivers: A synthesis report to the U.S. Army Corps of Engineers, Walla Walla District. Bird Research Northwest. Available on-line at www.birdresearchnw.org.

Kareiva, P., M. Marvier, and M. McClure. 2000. Recovery and management options for spring/summer Chinook salmon in the Columbia River basin. Science 290: 977-979.

Ledgerwood, R.D., B.A. Ryan, E.M. Dawley, E.P. Nunnallee, and J.W. Ferguson. 2004. A surface trawl to detect migrating juvenile salmonids tagged with passive integrated transponder tags. North American Journal of Fisheries Management 24:440-451.

Lyons, D.E. 2010. Bioenergetics-based predator-prey relationships between piscivorous birds and juvenile salmonids in the Columbia River estuary. Unpubl. Ph.D. dissertation, Oregon State University, Corvallis, Oregon. Available on-line at www.birdresearchnw.org.

Lyons, D.E., D.D. Roby, A.F. Evans, N.J. Hostetter, and K. Collis. 2011a. Benefits to Columbia River anadromous salmonids from potential reductions in avian predation on the Columbia Plateau. Report submitted to the U.S. Army Corps of Engineers, Walla Walla District. Bird Research Northwest. Available on-line at www.birdresearch.org.

Lyons, D.E., D.D. Roby, J.Y. Adkins, P.J. Loschl, L.R. Kerr, T.K. Marcella, A.F. Evans, N.J. Hostetter, K. Collis, D.R. Kuligowski, and B.P. Sandford. 2011b. Impacts of piscivorous birds on native anadromous fishes in the mid-Columbia River. Pages 49-80*in* Roby, D.D. (ed.). Impacts of avian predation on salmonid smolts from the Columbia and Snake rivers: A synthesis report to the U.S. Army Corps of Engineers, Walla Walla District. Bird Research Northwest. Available on-line at www.birdresearchnw.org.

Lyons, D.E., D.D. Roby, and K. Collis. 2007. Foraging patterns of Caspian terns and double-crested cormorants in the Columbia River estuary. Northwest Science 81:91-103.

Maranto, C.J., T.P. Good, F.K. Wiese, and J.K. Parish. 2010. Impact of the Potholes Reservoir Caspian tern breeding colony on out-migrating juvenile salmonids in the mid-Columbia River. Transactions of the American Fisheries Society 139:362-381.

Maranto, C.J., J.K. Parrish, D.P. Herman, A.E. Punt, J.D. Olden, M.T. Brett, and D.D. Roby. 2011. Use of fatty acid analysis to determine dispersal of Caspian terns in the Columbia River Basin, U.S.A. Conservation Biology 25: 736-746.

Marsh, D.M., W.D. Muir, R.W. Zabel, and D. Elliot. 2011. Alternative barging strategies to improve survival of transported juvenile salmonids [abstract]. Proceedings of the 2011 Anadromous Fish Evaluation Program Annual Review. U.S. Army Corps of Engineers, Walla Walla District. Nov. 28 – Dec. 1, 2011.

McClure, M.M., E.E. Holmes, B.L. Sanderson, and C.E. Jordon. 2003. A large-scale, multi-species status assessment: Anadromous salmonids in the Columbia River Basin. Ecological Applications 13: 964-989.

McMichael, G.A., R.A. Harnish, B.J. Bellgraph, J.A. Carter, K.D. Ham, P.S. Titzler, and M.S. Hughes. 2010. Survival and migratory behavior of juvenile salmonids in the lower Columbia River estuary in 2009. PNNL-19545, Pacific Northwest National Laboratory, Richland, WA.

Naughton, M.B., D.S. Pitkin, R.W. Lowe, K.J. So, and C.S. Strong. 2007. Catalog of Oregon seabird colonies. U.S. Department of Interior, Fish and Wildlife Service, Biological Technical Publication FWS/BTP-R1009-2007, Washington, D.C.

NOAA (National Oceanic and Atmospheric Administration). 2008. Endangered Species Act section 7(a)(2) consultation biological opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Consultation: Consultation on remand for operation of the Federal Columbia River Power System, 11 Bureau of Reclamation Projects in the Columbia Basin and ESA Section 10(a)(I)(A) permit for Juvenile Fish Transportation Program. Seattle, WA.

NOAA (National Oceanic and Atmospheric Administration). 2010. Endangered Species Act section 7(a) (2) consultation supplemental biological opinion: Supplemental consultation on remand for operation of the Federal Columbia River Power System, 11 Bureau of Reclamation Projects in the Columbia Basin and ESA Section 10(a) (I) (A) permit for Juvenile Fish Transportation Program. Seattle, WA.

NOAA (National Oceanic and Atmospheric Administration). 2011. Updated status of federally listed ESUs of West Coast salmon and steelhead. Available on-line at: http://www.nwr.noaa.gov/Publications/Biological-Status-Reviews/Salmon.cfm.

Roby, D.D., K. Collis, D.E. Lyons, D.P. Craig, J.Y. Adkins, A.M. Myers, and R.M. Suryan. 2002. Effects of colony relocation on diet and productivity of Caspian terns. Journal of Wildlife Management 66:662–673.

Roby, D.D., D.E. Lyons, D.P. Craig, K. Collis, and G.H. Visser. 2003. Quantifying the effect of predators on endangered species using a bioenergetics approach: Caspian terns and juvenile salmonids in the Columbia River estuary. Canadian Journal of Zoology 81:250-265.

Roby, D.D. (ed.). 2011. Impacts of avian predation on salmonid smolts from the Columbia and Snake rivers: A synthesis report to the U.S. Army Corps of Engineers, Walla Walla District. Bird Research Northwest. Available on-line at www.birdresearchnw.org.

Ryan, B.A., S.G. Smith, J.M. Butzerin, and J.W. Ferguson. 2003. Relative vulnerability to avian predation of juvenile salmonids tagged with passive integrated transponders in the Columbia River Estuary, 1998-2000. Transactions of the American Fisheries Society 132:275-288.

Schreck, C.B., T.P. Stahl, L.E. Davis, D.D. Roby, and B.J. Clemens. 2006. Mortality estimates of juvenile spring-summer Chinook salmon in the lower Columbia River and estuary, 1992-1998: Evidence for delayed mortality? Transactions of the American Fisheries Society 135: 457-475.

Sebring, S.H., R.D. Ledgerwood, B.P. Sandford, A. Evans, and G.M. Matthews. 2010a. Detection of passive integrated transponder (PIT) tags on piscivorous avian colonies in the Columbia River basin, 2008. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District. Available on-line atwww.nwfsc.noaa.gov.

Sebring, S.H., M.S. Morrow, R.D. Ledgerwood, B.P. Sandford, A. Evans, and G.M. Matthews. 2010b. Detection of passive integrated transponder (PIT) tags on piscivorous bird colonies in the Columbia River basin, 2009. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District. Available on-line atwww.nwfsc.noaa.gov.

Suryan, R.M., D.P. Craig, D.D. Roby, N.D. Chelgren, K. Collis, W.D. Shuford, and D.E. Lyons. 2004. Redistribution and growth of the Caspian tern population in the Pacific Coast region of North America, 1981-2000. Condor 106: 777-790.

Torbeck, C., J. Mainord, J. Whiteaker, and J.K. Fryer. 2009. Age and length composition of Columbia Basin Chinook and sockeye salmon and steelhead at Bonneville Dam in 2008. Columbia River Inter-Tribal Fish Commission Technical Report 09-05. Portland, OR. Available on-line at www.critfc.org.

USACE (U.S. Army Corps of Engineers), BPA (Bonneville Power Administration), and BOR (Bureau of Reclamation). 2007. Comprehensive analysis of the Federal Columbia River Power System and mainstem effects of Upper Snake and other tributary actions. U.S. Army Corps of Engineers, Portland, OR.

USFWS (U.S. Fish and Wildlife Service). 2005. Caspian tern management to reduce predation of juvenile salmonids in the Columbia River estuary, Final Environmental Impact Statement. U.S. Fish and Wildlife Service, Migratory Birds and Habitat Programs, Portland, OR.

Waples, R.S. 1991. Pacific salmon, *Oncorhynchus* spp., and the definition of "species" under the Endangered Species Act. Marine Fisheries Review 53:11-22.

Table 1. 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 (after Evans et al. 2011) and are corrected for tag detection efficiency and off-colony deposition of tags by cormorants. 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
Predation Rates	5.1%	3.7%	3.6%	2.7%	4.8%	13%	7.1%	11%

[1]Five ESA-listed Columbia River salmon and steelhead populations are not listed here. Lower Columbia River (LCR) and Upper Willamette River winter-run steelhead DPSs lack representative samples of PIT-tagged smolts to base analysis on. Portions of the LCR Chinook and coho 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 low (Lyons 2010).

Table 2. Percentage increases in the average annual population growth rate (λ) of selected salmon and steelhead ESUs for various levels of reduction in predation by the East Sand Island double-crested cormorant 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%	0.3%	0.2%	0.2%	0.4%	0.6%	0.5%	0.6%
	50%	0.6%	0.5%	0.4%	0.3%	0.8%	1.2%	1.0%	1.3%
	75%	0.9%	0.8%	0.6%	0.5%	1.2%	1.8%	1.5%	1.9%
	100%	1.2%	1.0%	0.9%	0.6%	1.6%	2.4%	1.9%	2.5%
25% Compensation	25%	0.2%	0.2%	0.2%	0.1%	0.3%	0.5%	0.4%	0.5%
	50%	0.5%	0.4%	0.3%	0.2%	0.6%	0.9%	0.7%	1.0%
	75%	0.7%	0.6%	0.5%	0.4%	0.9%	1.4%	1.1%	1.4%
	100%	0.9%	0.8%	0.6%	0.5%	1.2%	1.8%	1.5%	1.9%
50% Compensation	25%	0.2%	0.1%	0.1%	0.1%	0.2%	0.3%	0.2%	0.3%
	50%	0.3%	0.3%	0.2%	0.2%	0.4%	0.6%	0.5%	0.6%
	75%	0.5%	0.4%	0.3%	0.2%	0.6%	0.9%	0.7%	1.0%
	100%	0.6%	0.5%	0.4%	0.3%	0.8%	1.2%	1.0%	1.3%
75% Compensation	25%	0.1%	0.1%	0.1%	<0.1%	0.1%	0.2%	0.1%	0.2%
	50%	0.2%	0.1%	0.1%	0.1%	0.2%	0.3%	0.2%	0.3%
	75%	0.2%	0.2%	0.2%	0.1%	0.3%	0.5%	0.4%	0.5%
	100%	0.3%	0.3%	0.2%	0.2%	0.4%	0.6%	0.5%	0.6%

Table 3. Hypothetical maximum cumulative potential benefit (expressed as percentage increases in the average annual population growth rate [λ]) to steelhead DPSs originating above Bonneville Dam resulting from management to reduce predation by East Sand Island double-crested cormorants, 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 on the Columbia Plateau (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 on the Columbia Plateau.

Action	Steelhead DPS			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	0.8%	0.7%	0.8%	8,400	3%
67% Reduction in Predation by East Sand Island Double-crested Cormorants	1.6%	1.3%	1.7%	16,800	3%
Complete Elimination of Predation by East Sand Island Double-crested Cormorants	2.4%	1.9%	2.5%	25,200	3%
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.

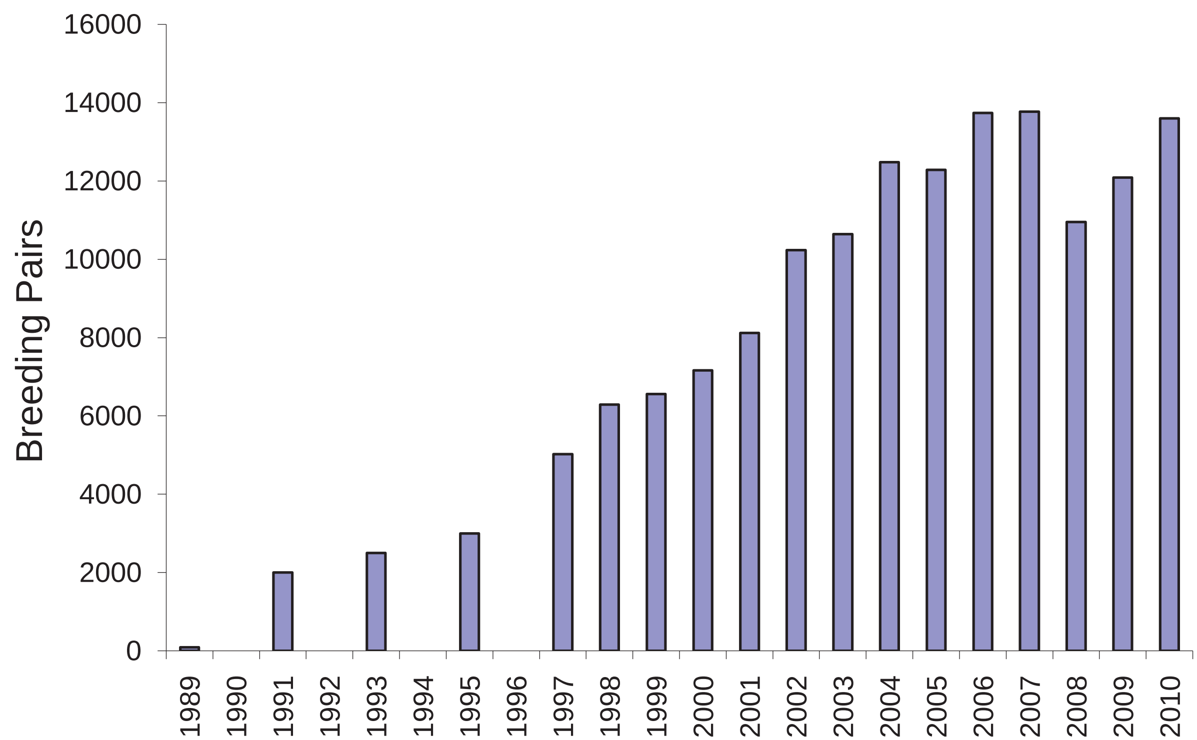

Figure 1. Size of the double-crested cormorant colony on East Sand Island since island colonization in 1989 (data from Carter et al. 1995, Anderson et al. 2004a, Naughton et al. 2007, Adkins and Roby 2010). No data are available for 1990, 1992, 1994, and 1996. Average size during 2007 – 2010 was 12,600 breeding pairs.

APPENDIX A

ASSESSMENT OF POTENTIAL BENEFITS TO LOWER COLUMBIA RIVER ANADROMOUS SALMONIDS

Data for the LCR Chinook salmon and coho salmon ESUs are still undergoing tabulation and review as of December, 2011. Results will be available when this report is finalized during the winter of 2012.

APPENDIX B

COMPARISON OF IMPACTS ON JUVENILE SALMONIDS FROM PREDATION BY DOUBLE-CRESTED CORMORANTS NESTING IN THE COLUMBIA RIVER ESTUARY BETWEEN THE "BASE" AND "CURRENT" PERIODS, AS FRAMED BY NOAA'S BIOLOGICAL OPINION ON THE OPERATION OF THE FEDERAL COLUMBIA RIVER POWER SYSTEM

SUMMARY: Recently completed analyses indicate that predation impacts of estuary double-crested cormorants on juvenile salmonids were greater than previously thought during the BiOp-defined "base" period and approached (were ≳90% of) "current" levels.

The 2008 Biological Opinion (BiOp) on the Federal Columbia River Power System (FCRPS) analyzed recovery actions using the framework of a "base" period (1981-2000), a "current" period (2001-2007), and the time when prospective recovery actions would be completed ("prospective" period; ca. 2018; NOAA 2008).Management to reduce predation on smolts by the East Sand Island double-crested cormorant colony is currently under consideration and information on the impacts of cormorants during the base and current periods may be important context for eventual policy decisions.

Predation impacts from double-crested cormorants on smolts in the estuary are not well known across the entire base period but it is known that cormorant populations in the estuary grew from negligible levels around 1980 (< 150 breeding pairs; Carter et al. 1995) to ~7,200 pairs in 2000. At the time the 2008 BiOp was being prepared, the impacts of the estuary cormorant population had not been fully analyzed for any portion of the base period (although data to allow this analysis had been collected during 1998-2000).

At the time of the 2008 BiOp, NOAA used bioenergetics-based estimates of predation to assess the impacts of estuary cormorants on smolt survival (Fredricks 2008; current period impacts updated for the 2010 Supplemental BiOp in Fredricks 2010). Smolt consumption data were available for 2003-2006 at that time and were used to assess "current" impacts. To assess the likely impacts of cormorants during the base period, NOAA scaled the per capita predation impacts of cormorants during 2003-2006 by the size of the estuary cormorant population during the base period relative to the size of the cormorant colony during the current period (Fredricks 2008). A second order adjustment factored in where within the estuary cormorants were nesting (Rice Island vs. East Sand Island) and incorporated known dietary differences between nesting locations. This scaling of impacts based on cormorant population size (and nesting location) resulted in an estimated impact during 1997-2000 of approximately 64% of the "current" period. This was a reasonable conclusion given the data available at the time.

Since the 2008 BiOp was drafted, additional bioenergetics-based analyses have been performed that estimate the actual smolt consumption levels of the estuary cormorant population during 1998-2000 (Lyons 2010). Additionally, recent efforts to assess benefits from potential reductions in predation by double-crested cormorants nesting on East Sand Island (this document) has identified the 2007-2010 period as the best description of "current" impacts of cormorants on salmonid populations, and the best predictor of future impacts if no management occurs to reduce cormorant predation. A comparison of these "base" and "current" periods using the most up-to-date information results in a somewhat different conclusion than was reached in

2008: the differences between base and current impacts are substantially smaller than would be expected based on differences in cormorant population size alone (Table B1).

The primary reason that data-based estimates of cormorant predation impacts during the base period approach those of the current period, despite a substantially smaller cormorant population during the base period, is differences in how much of the cormorant diet was made up of juvenile salmonids (Table B2).

It is not possible at this time to conclusively explain why cormorants relied on smolts to a greater extent during the base period, although availability of alternative prey and particularly marine forage fish were likely lower during that period (Emmett et al. 2006).

Predation rates on salmonid ESUs/DPSs by estuary cormorants that are derived from the recovery of passive integrated transponder (PIT) tags will be used to estimate potential benefits to ESA-listed salmonid populations in the upcoming benefits analysis document. Comparisons between base and current period cormorant impacts using these PIT tag-based predation rates are not straightforward due to few data available for the earlier period. PIT tag data were collected at Rice Island in 1998 and at East Sand Island in 1999-2000, but not at East Sand Island in 1998 (Ryan et al. 2003). Also, test tags were not sown at either colony in any year, so no data are available to estimate detection efficiency during these years. In addition, the available data summaries for the base period (Ryan et al. 2003) do not break down predation rates by specific DPS/ESU.

While recent (2007-2010) impacts of estuary cormorants appear to be only slightly greater than during the late 1990s, the intervening period (2001-2005) saw noticeably lower impacts of cormorant predation on smolt survival. The point estimates for smolt consumption by estuary cormorants was lower for these 5 years than for all years before or since (Figure B1).

Presumably alternative prey were more readily available in the estuary and near shore environment during this period, although definitive data are not available (but see Emmett et al. 2006).

REFERENCES

Emmett, R.L., G.K. Krutzikowsky, and P. Bentley. 2006. Abundance and distribution of pelagic piscivorous fishes in the Columbia River plume during spring/early summer 1998-2003: Relationship to oceanographic conditions, forage fishes, and juvenile salmonids. Progress in Oceanography 68: 1-26.

Fredricks, G. 2008. Base to current double crested cormorant consumption estimates for steelhead in the Columbia River estuary. Memorandum for Ritchie Graves, October 22, 2008.

Fredricks, G. 2010. Double-crested cormorant smolt predation in the Columbia River estuary (updated through 2009). Memorandum for Ritchie Graves, April 19, 2010.

Lyons, D.E. 2010. Bioenergetics-based predator-prey relationships between piscivorous birds and juvenile salmonids in the Columbia River estuary. Unpubl. Ph.D. dissertation, Oregon State University, Corvallis, Oregon. Available on-line at www.birdresearchnw.org.

NOAA (National Oceanic and Atmospheric Administration). 2008. Endangered Species Act section 7(a)(2) consultation biological opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Consultation: Consultation on remand for operation of the Federal Columbia River Power System, 11 Bureau of

Reclamation Projects in the Columbia Basin and ESA Section 10(a)(I)(A) permit for Juvenile Fish Transportation Program. Seattle, WA.

Ryan, B.A., S.G. Smith, J.M. Butzerin, and J.W. Ferguson. 2003. Relative vulnerability to avian predation of juvenile salmonids tagged with passive integrated transponders in the Columbia River Estuary, 1998-2000. Transactions of the American Fisheries Society 132: 275-288.

Table B1. Comparison of impacts on salmonids by the Columbia River Estuary double-crested cormorant population between the "Base" and "Current" periods, as calculated for the 2008 Biological Opinion, and as calculated using more recently available data (Lyons 2010).

	2008 BiOp		Benefits Analysis	
	Base Period	Current Period	Base Period	Current Period
Years	1997-2000	2003-2006	1998-2000	2007-2010
Methods	Pro-rated BIOE	Data-based BIOE	Data-based BIOE	Data-based BIOE
Estuary Population Size (pairs)	6,742	12,360	6,934	12,656
Total Smolt Consumption/year (millions)[1]	3.6 (64% of Current)	5.6	11.7 (97% of Current)	12.1
Steelhead Smolt Consumption/year (millions)[1]	0.53 (64% of Current)	0.83	0.96 (91% of Current)	1.06

[1]The 2008 BiOp expressed impacts in terms of predation rates (% of available smolts that were consumed). For simplicity, impacts are expressed here in terms of numbers consumed (does not require an estimate of the number of smolts available).

Table B2. Juvenile salmonid proportion (% biomass) of the East Sand Island cormorant diet.

	Base Period 1998-2000	Current Period 2007-2010
April-June	22%	16%
July	13%	3%

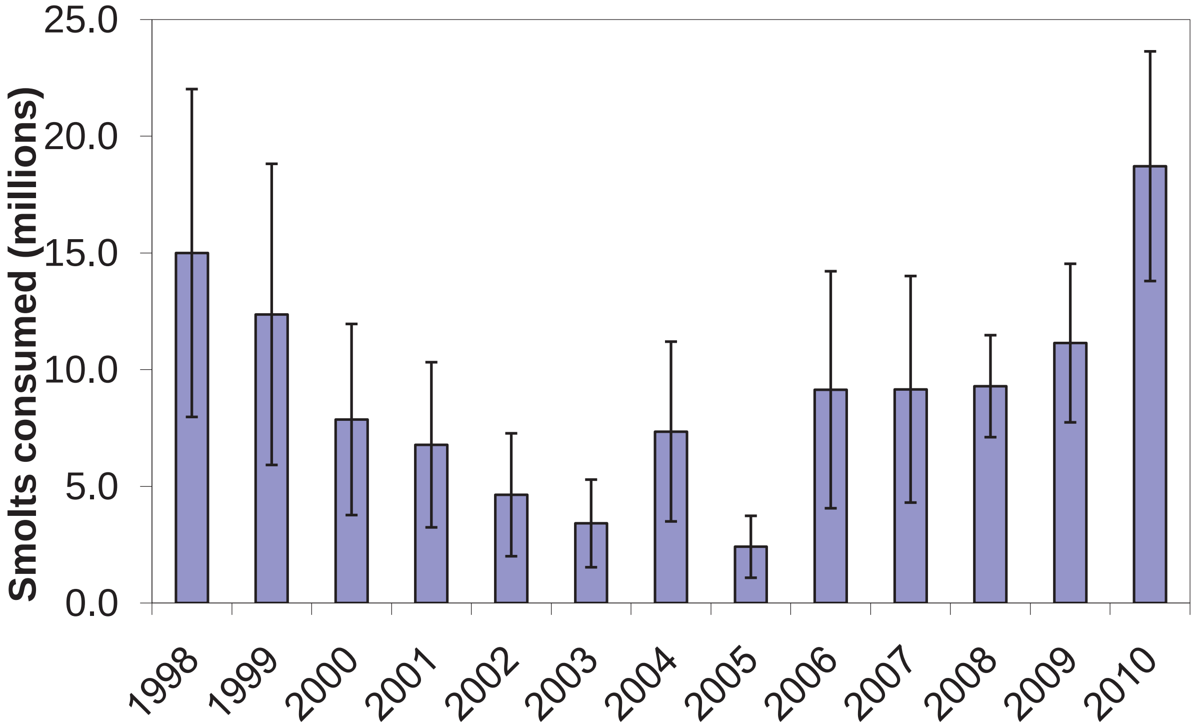

Figure B1. Bioenergetics-based estimates of annual smolt consumption (best estimate and 95% confidence interval) by double-crested cormorants nesting in the Columbia River estuary (Lyons 2010).