FEATURE

Caspian Tern Management to Increase Survival of Juvenile Salmonids in the Columbia River Basin: Progress and Adaptive Management Considerations

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Caspian tern *Hydroprogne caspia*. Photo credit: Daniel Roby.

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Predation by Caspian terns *Hydroprogne caspia* is a factor limiting the recovery of some Endangered Species Act-listed populations of salmonids from the Columbia River basin, especially steelhead *Oncorhynchus mykiss*. This prompted the development and implementation of two separate management plans, one in the Columbia River estuary and the other in the Columbia Plateau region, to reduce the impact of Caspian tern predation on smolt survival. Caspian terns nesting at managed breeding colonies within the basin were relocated to alternative nesting islands created for terns outside the basin. Both plans were successful in significantly reducing smolt losses to Caspian terns nesting at managed sites; however, new developments have led to regression in smolt survival gains associated with tern management. Adaptive management to prevent terns at managed colonies from relocating to nest elsewhere in the basin and to improve nesting opportunities for Caspian terns outside the basin are needed to maximize the survival benefits to Endangered Species Act-listed salmonids from management. Adaptive management is also necessary to ensure the long-term viability of the Pacific Flyway population of Caspian terns, whose breeding population has declined by more than 50% since the two management plans were implemented.

INTRODUCTION

Anadromous salmon (Chinook Salmon *Oncorhynchus tshawytscha*, Coho Salmon *O. kisutch*, Sockeye Salmon *O. nerka*) and trout (steelhead *O. mykiss*) are considered an invaluable natural resource in the Pacific Northwest and an icon of the quality of life in the region, but 13 of 20 populations of salmonids from the basin are listed as threatened or endangered under the U.S. Endangered Species Act (ESA; Good et al. 2005). Management of avian predators is one of many possible approaches to enhancing the survival of out-migrating juvenile salmonids (smolts) in the Columbia River basin. This approach, however, has been highly controversial both within and among the various publics in the region. Most fisheries managers consider the "4 Hs" (over*harvest*; alteration of the river hydrology to allow *hydroelectric* power production and flood control; other forms of freshwater *habitat* loss; and resource competition, genetic loss, and disease transmission from fish reared in *hatcheries*) to be the main factors responsible for dramatic declines in salmonids within the basin (Hilborn 1989; NRC 1996; Lichatowich 1999). The magnitude of smolt losses to predation by some piscivorous colonial waterbirds in the Columbia River basin, however, surprised many fisheries managers and prompted calls for swift management action to reduce those losses. Consensus among managers, scientists, and stakeholders on the science and policy of whether and to what extent avian predation should be managed has been elusive. Some have viewed management of avian predation as a diversion of limited resources from addressing the root causes of salmonid declines (i.e., the 4 Hs). Others have perceived smolt losses to avian predators as an existential threat to certain beleaguered stocks and populations of ESA-listed salmonids. These divergent viewpoints have put the science of avian predation on salmonids in a political hotseat.Although generally not considered a leading cause of salmonid declines (Nelson et al. 1991), federal resource managers have determined that avian predation, and specifically predation by Caspian terns *Hydroprogne caspia*, is a factor limiting the recovery of some salmonid populations in the Columbia River basin, especially steelhead (USFWS 2005, 2006; USACE 2014). This prompted the development of two separate management plans to reduce the impact of Caspian tern predation on smolt survival, one in the Columbia River estuary and the other further inland in the Columbia Plateau region. These two plans were part of a comprehensive management strategy to restore ESA-listed salmonid populations throughout the basin (NMFS 2008, 2019). What follows is an assessment of the progress made toward the stated goals and objectives of each management plan, as well as adaptive management actions that could be undertaken to maximize the benefits to salmonid populations and minimize the risks to the managed bird population (see Roby et al. 2021 for the full complement of data and results associated with this work).

NATURAL HISTORY OF CASPIAN TERNS

Caspian terns have nearly a cosmopolitan distribution, which includes several distinct populations in North America (Cramp 1985; Wires and Cuthbert 2000; Cuthbert and Wires 2020). Caspian terns nesting in the Columbia River basin are part of the Pacific Flyway population of North America, which prior to management, consisted of about 19,000 breeding pairs or about one-fourth of the North American metapopulation, and roughly one-tenth of the worldwide population (Suryan et al. 2004; Lawes et al. 2022). The Pacific Flyway population, which includes both coastal and inland breeding colonies, breeds along the Pacific Coast from Alaska to Baja California and inland to the Continental Divide (Figure 1).

During the first half of the 20th century, breeding colonies of Caspian terns in the Pacific Flyway were mostly at inland lakes, marshes, and reservoirs, with a few small colonies on coastal bays and estuaries, and many of the inland colonies were in decline and of conservation concern (Gabrielson and Jewett 1940; Bent 1947). During the latter half of the 20th century, however, breeding habitat/distribution shifted from inland water bodies to coastal sites (Penland 1981; Suryan et al. 2004), including the Columbia River estuary. The Pacific Flyway population increased from about 3,500 pairs in 1960 to about 14,000 pairs in 2000 (Gill and Mewaldt 1983; Suryan et al. 2004). By the end of the 20th century, the Pacific Flyway population of Caspian terns nested mostly on sandy islands along the Pacific Coast, including dredged material disposal sites (Suryan et al. 2004), and in more urban environments, Caspian terns began nesting on warehouse rooftops and on vacant barges.

Historically, Caspian terns typically breed in small colonies (generally <100 breeding pairs) in association with other colonial waterbirds, especially gulls *Larus* spp. (Cuthbert and Wires 2020). Caspian terns are ground nesters, preferring island nesting habitat that is unvegetated (Quinn and Sirdevan 1998), isolated, and free from mammalian nest predators (Cuthbert and Wires 2020). Tern nests consist of a shallow scrape in areas of sparsely vegetated sand, gravel, or other fine debris, habitat that is largely ephemeral (e.g., created or eliminated by winter storms, drought, vegetation succession, and/or human activity). Consequently, Caspian terns have adapted to the ephemeral character of their nesting habitat by shifting frequently among nesting colony sites, which is born out in observations of marked individuals being resighted at different colony locations throughout the Pacific Flyway, both within and between breeding seasons (Suzuki et al. 2018).

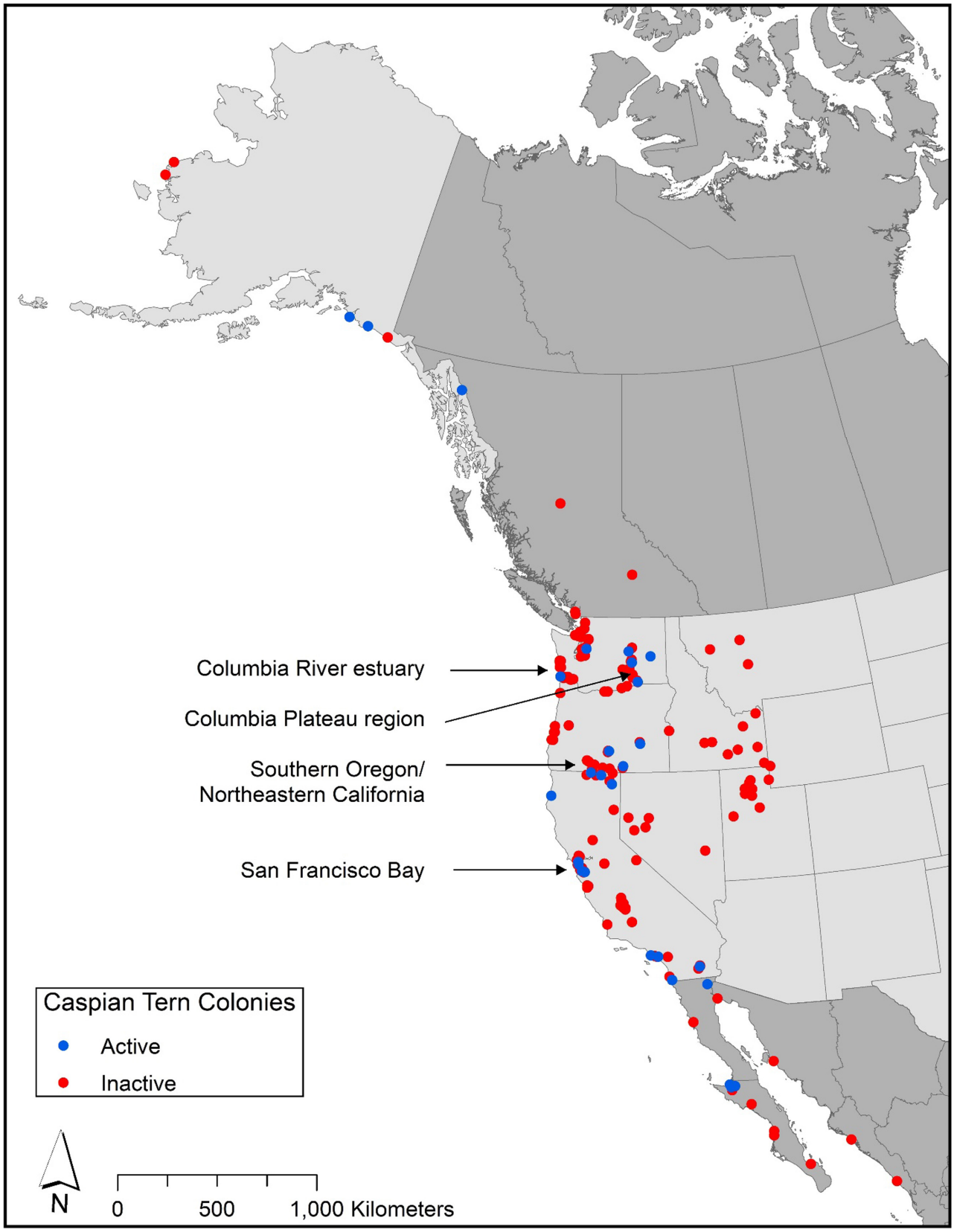

Figure 1. Distribution of Caspian tern breeding colonies (blue dots = active colonies; red dots = inactive colonies) in the Pacific Flyway population as of 2017. "Inactive" refers to colony sites that can no longer support tern nesting due to changes to the site that limit or preclude successful tern nesting. Regions are labeled where some tern nesting habitat was reduced/eliminated (Columbia River estuary, Columbia Plateau region) and some tern nesting habitat was created/enhanced (southern Oregon/ northeastern California region, San Francisco Bay) as part of management plans for Caspian terns in the Columbia River basin. Data from Suzuki et al. (2018).

Caspian terns are almost entirely piscivorous and forage by plunge-diving to capture fish at or near the surface of the water (Cuthbert and Wires 2020). The species forages in a variety of marine, brackish, and freshwater habitats, usually on or near protected water bodies (e.g., lakes, rivers, and coastal bays), where forage fish 10–25 cm in length are readily available at the surface (Lyons et al. 2005; Cuthbert and Wires 2020). Caspian terns are generalist foragers, feeding on the most available forage fishes proximate to their breeding colonies (Lyons et al. 2005). Early work investigating the foraging behavior and diet of piscivorous colonial waterbirds in the Columbia River basin, including Caspian terns, revealed that the diet of fish-eating birds varied significantly by colony location. Terns nesting in the marine zone of the Columbia River estuary were more reliant on marine forage fishes (e.g., Northern Anchovy *Engraulis mordax*, Pacific Herring *Clupea pallasii*) and less reliant on out-migrating juvenile salmonids in comparison to terns nesting in the freshwater zone of the estuary (Simenstad et al. 1990; Collis et al. 2002).

PREDATION BY CASPIAN TERNS ON COLUMBIA BASIN SALMONIDS

Research on the impact of Caspian tern predation on the survival of outmigrating salmonids in the Columbia River basin was initiated in 1997. At that time the largest known breeding colony of Caspian terns in the world (~9,400 breeding pairs) was located on Rice Island, an artificial dredged material disposal island in the freshwater zone of the Columbia River estuary. The colony at Rice Island was first detected in 1985 and grew rapidly in the subsequent decade (Collis et al. 2002; Suryan et al. 2004). By 1997, about two-thirds of the Pacific Flyway population of Caspian terns nested on Rice Island (Suryan et al. 2004). This concentration of Caspian terns at a single colony site resulted in conservation concern for the Pacific Flyway population. The terns nesting at this megacolony were also having a significant impact on survival of salmonid smolts. Up to 16 million smolts were consumed annually by Caspian terns nesting on Rice Island (Roby et al. 2003) and predation losses consisted of up to 23% of smolts that survived to the estuary from some ESA-listed salmonid populations (Roby et al. 2021, appendix B). Juvenile steelhead were found to be especially susceptible to predation by Caspian terns nesting on Rice Island, likely due to size-dependent selection (juvenile steelhead are generally larger than other salmonid outmigrants). Also, juvenile steelhead are more surface oriented than other juvenile salmonids during outmigration (Collis et al. 2001; Hostetter et al. 2023), a trait that makes them more susceptible to predation by plunge-diving terns.

A comprehensive program to investigate the impacts on smolt survival from predation by piscivorous colonial waterbirds (i.e., Caspian terns, double-crested cormorants *Nannopterum auritum*, American white pelicans *Pelecanus erythrorhynchos*, and several gull species) throughout the Columbia River basin was initiated following the study of the Rice Island tern colony (see Roby et al. 2021). Caspian terns nesting at two much smaller colonies in the Columbia Plateau region, namely on Goose Island in Potholes Reservoir and on Crescent Island on the mid-Columbia River, were also having a significant impact on survival of some populations of juvenile salmonids, particularly steelhead from the threatened Upper Columbia River and Snake River populations. Predation rates on steelhead by Caspian terns nesting at these two up-river colonies were of the same magnitude as those by terns nesting in the Columbia River estuary, with upwards of 20% of steelhead smolts consumed annually by terns in some years (Evans et al. 2019, 2022). This was unexpected given that the number of terns nesting at these two inland colonies combined (in the hundreds of breeding pairs) was an order of magnitude less than the number of terns nesting in the estuary (in the thousands of breeding pairs; Collis et al. 2002; Evans et al. 2012).

The cumulative impacts of Caspian tern predation on smolt survival in the basin (see Roby et al. 2021) were mostly a result of the confluence of two anthropogenic factors that continue to operate in the basin (Figure 2). First, avian predators are provided a reliable and stable food supply during the nesting period by way of over a 100 million hatchery-reared juvenile salmonids released into the river each year (Collis et al. 2001; CBR 2023). Second, the preferred nesting habitat for Caspian terns was provided by river impoundments that created islands on and near the Columbia River, plus the disposal of dredged material from shipping channels (i.e., sand, the preferred nesting substrate for terns) on islands that are free from mammalian nest predators (Collis et al. 2002; Roby et al. 2021). Those factors contributed to a dramatic increase during 1980–2010 in the number of Caspian terns nesting in the basin, as well as their impacts on several ESA-listed populations of salmonids.

Understanding the degree to which avian predation limits fish survival is paramount in determining the efficacy of any management actions aimed at increasing fish survival by decreasing tern predation. In particular, understating whether reductions in tern predation rates are associated with higher rates of fish survival (i.e., tern predation adds to total mortality) or if most fish consumed by terns are destined to die regardless of avian predation (i.e., tern predation is compensated for by other mortality factors). Previously published research indicated that predation by terns on steelhead smolts was an additive source of smolt mortality during the smolt life stage and a partially additive source of mortality to adulthood, with significantly more smolts estimated to survive outmigration to the Pacific Ocean and to return to Bonneville Dam as adults in the absence of tern predation (Payton et al. 2020).

MANAGEMENT TO REDUCE CASPIAN TERN PREDATION ON SMOLTS IN THE COLUMBIA BASIN

Regional fisheries resource managers prepared two management plans whose goal was to reduce the impact of Caspian tern predation on ESA-listed salmonid populations; one plan focused on management in the Columbia River estuary and the other focused on management in the Columbia Plateau region. The objective of both tern management plans was to greatly reduce the size of selected Caspian tern breeding colonies (hereafter, "managed" colonies or sites) and redistribute terns from these managed sites to alternative colony sites outside the Columbia River basin (hereafter, "alternative" colonies or sites). A total of 13 alternative tern colony sites, consisting of islands ranging in size from 0.14 ha (0.35 acres) to 0.80 ha (2 acres), were constructed or enhanced to provide suitable Caspian tern nesting habitat in out-of-basin areas where tern predation on fishes of conservation concern was expected to be minimal. This management approach was selected to significantly reduce mortality rates for several ESA-listed salmonid populations in the Columbia Basin, while ensuring the

Figure 2. Anthropogenic factors contributing to the increase in the number of nesting Caspian terns and their impacts on Endangered Species Act-listed juvenile salmonids in the Columbia River basin. Photos (left to right starting in the upper left) show: (1) dredged material deposition on Rice Island in the Columbia River estuary; (2) terns nesting on dredged material on East Sand Island in the Columbia River estuary; (3) a mass release of hatchery-reared juvenile salmonids into the Columbia River; (4) a tern with a juvenile salmonid in its bill flying over the East Sand Island tern colony.

long-term conservation of the Pacific Flyway population of Caspian terns (USFWS 2005, 2006; USACE 2014).

The efficacy of management plans to relocate Caspian terns from managed sites in the Columbia River basin to alternative sites outside the basin was based on the following premises: (1) terns can be prevented from nesting at managed sites by eliminating/reducing the area of bare sand habitat, (2) suitable sites for tern breeding colonies are limited and can be created/enhanced through habitat management at alternative sites, (3) terns can be attracted to nest at alternative colony sites using social attraction techniques (i.e., tern decoys and audio playback of tern vocalizations; see below), and (4) once a tern colony has become established at an alternative site, limiting factors to tern colony size and nesting success (e.g., nest predation, vegetation encroachment) can be managed to sustain the colony over the long-term. If met, these criteria would ensure that the habitat provided at alternative sites would be used by nesting terns and thereby compensate for the loss of nesting habitat at managed sites within the basin, which would avoid putting the regional tern population at risk (Roby et al. 2002).

Efforts to restore breeding colonies of several tern species *Sterna* spp. at sites along the coast of Maine (Kress 1983, 1998) and in the Great Lakes region (Lampman et al. 1996; Quinn et al. 1996) have been successful, requiring four key elements for their success: (1) creating bare sand habitat either by vegetation management or placement of fine-grained substrates favored by nesting terns (Quinn and Sirdevan 1998), (2) deploying social attraction (Kress 1983) on the restored nesting habitat, (3) controlling nest predators (both avian and mammalian) that are observed depredating tern eggs and chicks at the site, and (4) close monitoring at the colony to identify and adaptively manage factors limiting colony restoration (Figure 3; Kress 1998; Kress and Jackson 2015; Scopel and Diamond 2017). These studies did not, however, attempt to relocate tern colonies from one site to another (requiring nest dissuasion actions at the managed site, as defined here), nor did they investigate changes in tern nesting success, diet, and foraging ecology associated with relocation of breeding terns from one colony site to another, key unknowns if tern management were to be undertaken in the Columbia River basin.

Figure 3. Components of restoring Caspian tern colonies as part of Caspian tern management in the Columbia River basin. Photos (left to right starting in the upper left) show: (1) preparation of bare sand nesting habitat for terns; (2) social attraction using tern decoys and audio payback systems broadcasting tern vocalizations; (3) control of tern nest predators (e.g., gulls) that limit tern colony size and nesting success; (4) close colony monitoring of the tern colony on East Sand Island used to assess management outcomes and inform adaptive management decisions.

As a precursor to management to relocate nesting terns from the Columbia River estuary to alternative sites outside the basin, a pilot study was implemented during 1999–2001 to determine whether the Caspian tern colony on Rice Island could be relocated to a different colony site in the estuary and if changes in colony location would affect diet composition and nesting success of the relocated terns (USACE 1999). It was hypothesized that terns nesting on East Sand Island, located in the marine zone of the estuary at river kilometer (rkm) 8, would be more reliant on marine forage fish and less reliant on juvenile salmonids as compared to terns nesting on Rice Island, located in the freshwater zone of the estuary at rkm 34 (Simenstad et al. 1990; Roby et al. 2021). The study included (1) implementation of all the tern colony restoration elements described above at the receiving site (East Sand Island), and (2) testing of nest dissuasion methods (i.e., vegetation plantings and installation of vertical silt fence rows; Pochop et al. 2001) on Rice Island as a means to discourage terns from nesting on Rice Island so that the displaced terns would relocate to nest on the prepared colony site on East Sand Island (Roby et al. 2002). During the first year of this pilot study (1999), 1,400 breeding pairs of Caspian terns were dissuaded from nesting on Rice Island and were attracted to nest on East Sand Island. By 2001, the entire breeding colony that formerly nested on Rice Island had relocated to East Sand Island (Roby et al. 2002). Diet studies indicated that a shift in colony location of just 26 rkm resulted in terns consuming significantly fewer juvenile salmonids; the proportion of salmonids in the tern diet at Rice Island was 77–90%, whereas the proportion at East Sand Island was 33–47% (Roby et al. 2002). The managed relocation of the Caspian tern colony from Rice Island to East Sand Island reduced tern predation on salmonids from over 11 million smolts consumed annually to 4–7 million smolts annually during 2001–2008 (Lyons 2010). Nesting success of terns on East Sand Island was found to be higher than at Rice Island, suggesting that moving the tern colony did not have a negative impact on the tern population (Roby et al. 2002). This pilot study demonstrated that Caspian tern colonies could be readily relocated using the methods described above, that the relocated colony could be as productive as the source colony, and that by changing where terns nest you could dramatically change both diet composition and impacts on fish populations of conservation concern.

Management in the Columbia River Estuary

Despite the benefits to juvenile salmonid survival from relocating the Caspian tern colony in the Columbia River estuary from Rice Island to East Sand Island, smolt consumption by Caspian terns nesting on East Sand Island was estimated at ~4–7 million smolts/year (Lyons 2010). Fisheries managers considered this magnitude of predation losses in the estuary to be too high, prompting development of a plan to reduce the size of the East Sand Island tern colony by more than half and to relocate displaced terns to restored colony locations outside the basin. The management plan entitled, "Caspian Tern Management Plan to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary" (hereafter, "estuary management plan" or EMP; USFWS 2005, 2006) sought to reduce the size of the East Sand Island tern colony by reducing the area of tern nesting habitat provided on the island from ~2.4 to 0.4 ha (1 acre; see Figure 4). Concurrently, alternative tern colony sites would be created or restored outside the Columbia Basin as compensation for the reduction in tern nesting habitat on East Sand Island (Figure 4; USFWS 2005, 2006). As part of the plan, adaptive management would be implemented if terns displaced from East Sand Island attempted to nest at other sites within the Columbia River estuary (i.e., on Rice Island or other dredged material disposal sites in the upper estuary) where tern predation rates on juvenile salmonids were known to be higher (Roby et al. 2003). The objective of the EMP was to redistribute approximately 60% of the East Sand Island tern colony to alternative sites outside the Columbia River basin, thereby reducing tern predation rates on juvenile steelhead and other salmonid stocks in the Columbia River estuary by a similar percentage (USFWS 2005, 2006). The managed reduction in tern nesting habitat was expected to result in a tern colony size on East Sand Island of between 3,125 and 4,375 breeding pairs, which was considered by fisheries managers to be a reasonable balance between impacts to salmonid smolt survival in the estuary and impacts to the Caspian tern population in the Pacific Flyway (USFWS 2005, 2006).

Implementation of the EMP was initiated in 2008, with nesting habitat for Caspian terns on East Sand Island incrementally reduced as alternative nest sites for terns were built

Figure 4. Efforts to reduce Caspian tern nesting habitat on East Sand Island and to create alternative tern nesting habitat outside the Columbia River basin. Photos (left to right starting in the upper left) show: (1) the tern colony site on East Sand Island prior to the managed reduction in area of tern nesting habitat; (2) vegetation and vertical fencing used to restrict the area of tern nesting habitat on East Sand Island; (3) construction of a tern nesting island in a temporarily drained impoundment in Tule Lake National Wildlife Refuge, California, as alternative nesting habitat for terns displaced from East Sand Island; (4) an island constructed as alternative nesting habitat for terns on Malheur Lake, Malheur National Wildlife Refuge, Oregon.

outside the basin. A total of nine alternative tern colony sites were constructed outside the Columbia Basin as part of the estuary management plan, eight of them in southern Oregon/northeastern California (hereafter, the "SONEC" region; Roby et al. 2021) and one in Fern Ridge Reservoir in the southern Willamette Valley, Oregon. Once the islands were built, efforts were made to attract terns to nest at the alternative sites using habitat management, social attraction, and predator control (Roby et al. 2021), while at the same time monitoring the outcome of these management actions at both the managed and alternative sites to assess their effectiveness in meeting the objectives of the plan.

The estuary management plan was successful in reducing the size of the Caspian tern colony on East Sand Island to the target size (3,125–4,375 breeding pairs), and thereby reducing predation rates on ESA-listed salmonid populations by terns nesting on East Sand Island. The target for tern colony area on East Sand Island (0.4 ha or 1 acre) was first achieved in 2015; however, the tern colony size did not immediately reach the target size for number of breeding pairs because terns initially adapted to the reduction in nesting habitat by nesting at higher densities (Roby et al. 2021). The target for number of breeding pairs was first reached in 2017, but this was at least partly attributable to complete colony failure (i.e., no fledged young produced) and subsequent colony abandonment during that and several subsequent years. These colony failures were associated with increases in disturbance to the colony by bald eagles *Haliaeetus leucocephalus* and, especially, to nest predation on tern eggs and chicks by gulls during eagle disturbances to the colony (Collar et al. 2017; Roby et al. 2021). During 2015–2022, the average size of the Caspian tern colony on East Sand Island (3,833 breeding pairs) was 58% less than during the pre-management period (9,079 breeding pairs during 2000–2007), and the reduction in colony size was associated with a 77% and 66% reduction in predation rates on Snake River and Upper Columbia River steelhead, respectively (Table 1). Estimates of total smolt consumption (all species/stocks combined) by Caspian terns nesting on East Sand Island declined by 40%, from about 5 million smolts annually during the pre-management period to about 3 million smolts in 2019, the last year during the management period when smolt consumption was measured (Roby et al. 2021).

Caspian terns nested at all eight of the alternative sites that were constructed in the SONEC region in the first breeding season after island construction was complete, the island was surrounded by water (i.e., islands were constructed in lakes or impoundments that are subject to drought or occasionally drained for irrigation purposes), and social attraction was deployed. On average, the alternative sites in the SONEC region accommodated a total of 870 breeding pairs of terns in the years following management, nearly three times the number of terns that nested in that region prior to management (Roby et al. 2021). Resightings of previously banded Caspian terns indicated that most terns that initially recruited to these alternative sites to nest were immigrants from the Columbia River estuary, located nearly 500 km away. Despite the initial success in relocating some Caspian terns from the estuary to alternative sites in the SONEC region, three of the alternative sites are no longer available as Caspian tern nesting habitat. Also, several environmental factors are limiting the size and nesting success of Caspian tern colonies at the remaining alternative sites, including drought, accessibility by predators, and vegetation encroachment (Roby et al. 2021).

Adaptive management using the nest dissuasion techniques described above was necessary in each year of management to prevent terns from nesting outside the designated 0.4-ha (1-acre) colony area on East Sand Island and at the former colony site on Rice Island. Preventing terns from returning to nest on Rice Island was of particular importance to the success of the estuary management plan, because per capita (per bird) predation rates by terns nesting on Rice Island and other islands in the freshwater zone of the estuary are known to be 2–3 times greater than those of terns nesting on East Sand Island in the marine zone of the estuary (Roby et al. 2002, 2021). In 2022, terns that attempted to nest on Rice Island consumed an estimated 2.3% and 2.7% of Snake River and Upper Columbia River steelhead, respectively, prior to being successfully hazed off the island by fisheries managers. These results demonstrated that even small numbers of terns (less than 1,000 individuals) prospecting on Rice Island for a relatively brief period (<3 weeks) can have a measurable impact on smolt survival, offsetting the benefits of managing the tern colony on East Sand Island (Evans et al. 2023).

Although management of the East Sand Island tern colony has been successful in reducing colony size and steelhead predation rates as stipulated in the estuary management plan, the overall success of the EMP remains equivocal.

Table 1. Caspian tern colony acreage, colony size, and average annual predation rates (95% credible intervals) on Snake River and Upper Columbia River steelhead during the pre-management and management periods at the managed colony site on East Sand Island in the Columbia River estuary. Colony acreage, colony size, and predation rates are averages for the pre-management period (2000–2007) and the management period (2015–2022), after the target colony area of 1.0 acres (0.4 ha) had been reached. Data are from Roby et al. (2021), Appendix B, and Evans et al. (2023).

Managed Site	Pre-management	Management	% Change
	Colony area (acres)		
East Sand Island	5.8	1.0	83% decrease
	Colony size (number of breeding pairs)		
East Sand Island	9,079	3,833	58% decrease
	Predation rate–Snake River steelhead		
East Sand Island	25.3% (22.7–28.3%)	5.9% (5.2–6.6%)	77% decrease
	Predation rate–upper Columbia River steelhead[a]		
East Sand Island	17.2% (15.2–19.5%)	5.8% (5.2–6.8%)	66% decrease

[a]Predation rate data not available in 2001.

As a result of management, some Caspian terns have relocated to nest and roost in the upper Columbia River estuary, where per capita predation rates are 1–3 times higher (Roby et al. 2021), as opposed to the alternative colony sites constructed outside the basin. Drought conditions and other limiting factors have rendered some of the alternative colony sites unsuitable for successful tern nesting in some years and reduced the numbers of terns that have been attracted away from the Columbia River estuary to nest. Additionally, the recent and ongoing increase in bald eagle disturbances at the East Sand Island tern colony and associated increase in predation on tern nests by gulls has led to complete nesting failure (i.e., no young terns fledged from the colony) in 5 out of the past 7 years (2017–2022; Evans et al. 2023), which is causing terns to seek nesting opportunities elsewhere in the estuary. Given adaptive management that is currently underway to prevent terns from nesting on islands in the upper estuary, the recent major declines in colony size and nesting success at the East Sand Island colony, and the lack of suitable alternative colony sites where large numbers of Caspian terns can nest successfully, the Pacific Flyway population of Caspian terns is now at risk of a dramatic and persistent decline (see below).

Management in the Columbia Plateau Region

An investigation of the impacts of Caspian tern predation on smolt survival in the Columbia Plateau region indicated that terns nesting at the two largest colonies in the region, those on Goose Island in Potholes Reservoir and on Crescent Island on the Columbia River, were having a significant impact on the survival of ESA-listed steelhead (Lyons et al. 2011; Payton et al. 2020; Evans et al. 2022). Fisheries managers deemed that the predation impacts from terns nesting at these two inland colonies warranted management action, and the plan entitled, "Inland Avian Predation Management Plan" (hereafter, "inland management plan" or IMP) was developed and implemented beginning in 2014, with a commitment to continue management activities for a 5-year period (USACE 2014). The overriding goal of the IMP was to increase survival of ESA-listed juvenile salmonids by greatly reducing the size of or eliminating the two largest Caspian tern colonies in the region (USACE 2014). This objective was to be achieved through the following:

- Altering the habitat at the two managed colony sites to create unfavorable nesting conditions for Caspian terns (Figure 5).
- Conducting daily active hazing at the managed sites to discourage Caspian terns from nesting on either island (Figure 5).
- Collecting a limited number of Caspian tern eggs (under permit) to prevent colony formation at the managed sites.
- Creating/enhancing nesting habitat for Caspian terns at alternative sites in San Francisco Bay, California, and actively attracting terns to nest at these alternative sites.
- Conducting adaptive management to limit Caspian terns from forming new colonies and/or expanding existing colonies within the Columbia Plateau region.
- Monitoring the outcomes of management to determine progress toward plan objectives (USACE 2014).

The IMP established not-to-exceed targets or triggers for colony size and population-specific predation rates on juvenile salmonids at both managed and unmanaged tern colonies in the Columbia Plateau region. One anticipated consequence of management was that terns displaced from the two managed colonies might nest elsewhere in the Columbia Plateau region. At the time that management commenced in 2014, there were four small tern colonies in the region that were not subjected to management (Roby et al. 2015), as well as other locations where tern colonies might become established. As part of the inland management plan, adaptive management to reduce or eliminate tern nesting at other sites was to commence if these triggers were reached, such that smolt survival gains associated with management at Goose and Crescent islands were not offset by increases in predation at other sites within the region. These triggers were for individual tern colonies and for the regionwide tern population and were based on 3-year averages of colony size and population-specific predation rates on juvenile salmonids. For colony size, adaptive management was to commence if a colony exceeded 40 breeding pairs, or if the regional breeding population of terns was greater than 200 breeding pairs (USACE 2014). Similarly, adaptive management would commence if colony-specific predation rates exceeded 2% for a particular ESA-listed salmonid population, or if the region-wide (all tern colonies combined) predation rate surpassed 5% for a salmonid population (USACE 2014).

Management of the Caspian tern colonies on the Columbia Plateau region began in 2014 on Goose Island and in 2015 on Crescent Island. Nest dissuasion efforts at these two managed sites were successful, with the colony at Crescent Island being completely abandoned from 2015 (the first year of management) to 2020 and the colony on Goose Island being mostly abandoned during 2014 (the first year of management) to 2022 (Roby et al. 2021; Evans et al. 2023). Terns nesting at Goose Island showed high fidelity to that colony site (i.e., prospecting terns attended the colony in each year during the management period), requiring intensive in-season active nest dissuasion (i.e., human hazing) and egg collection to prevent colony formation, perhaps due to the lack of other suitable nesting opportunities for terns in the immediate vicinity. Regardless, nest dissuasion efforts achieved the management objective of reducing average colony size at both sites to <40 breeding pairs (Table 2). The predation rate targets were also reached at both managed colonies for the stocks that were of greatest risk to tern predation, namely Upper Columbia River and Snake River steelhead, with declines in predation rates on these populations ranging from 93% to 96% (Table 2).

The alternative colony sites that were created/enhanced for Caspian terns in San Francisco Bay as part of the IMP were colonized in the first breeding season after completion (2015; Hartman et al. 2019); however, resightings of previously banded terns indicated that most terns that initially colonized the alternative sites in San Francisco Bay were from other extant colonies in the bay area (Roby et al. 2021). In contrast, the alternative colony sites constructed for tern nesting in the SONEC region as part of the EMP saw a considerable influx of terns that had been banded at Crescent or Goose islands and displaced by management (Roby et al. 2021).

Colony size and smolt predation rates by Caspian terns nesting at the managed colony sites in the Columbia Plateau region were greatly reduced (Table 2), but most of the displaced terns recruited to extant or incipient colony sites within the region. For example, coincident with Caspian terns abandoning the Crescent Island colony during the first year of management, a tern colony at the Blalock Islands in John Day Reservoir, located 65 rkm downstream from Crescent Island, increased

Figure 5. Efforts to prevent Caspian terns from nesting on Goose Island and Crescent Island as part of the Caspian tern management plan in the Columbia Plateau region. Photos (left to right starting in the upper left) show: (1) passive nest dissuasion (i.e., stakes, rope, and flagging) to dissuade tern nesting on Goose Island (the birds visible in the photo are ring-billed gulls *Larus delawarensis*, which are not deterred from nesting amidst stakes, rope, and flagging); (2) passive nest dissuasion (i.e., fencing, rope, flagging, and willow plantings) used to dissuade terns from nesting on Crescent Island; (3) human hazing to dissuade terns from nesting/roosting on Goose Island during daylight hours; (4) using a green laser during crepuscular hours to dissuade terns from remaining on Goose Island overnight.

more than 10-fold, from a pre-management average of 57 breeding pairs to 677 breeding pairs in 2015 (Roby et al. 2021). Resightings of banded Caspian terns at the Blalock Islands confirmed that most of the terns were from the managed colony on Crescent Island (Roby et al. 2021). During 2015–2020, annual predation rates on Upper Columbia River and Snake River steelhead exceeded the 2% management target at the Blalock Islands, averaging 4.3% and 3.8%, respectively (Collis et al. 2021: Roby et al. 2021, Appendix B). This increase in tern predation rates at the Blalock Islands prompted adaptive management in 2021–2022 by raising the John Day Reservoir elevation during the tern breeding season to flood tern nesting habitat at that site (USACE et al. 2020a, 2020b), which prevented all tern nesting at the Blalock Islands during those years. Beginning in 2021 and coincident with adaptive management at the Blalock Islands, Caspian terns started to nest at the site of a small former colony on Badger Island (located 2 rkm upstream of Crescent Island) and reinitiated nesting on Crescent Island, likely due to the termination of nest dissuasion activities and the reestablishment of a gull colony at that site (Evans et al. 2022, 2023). These two colonies have since grown to become the largest Caspian tern colonies in the Columbia Plateau region in 2022 (267 and 149 breeding pairs at Badger Island and Crescent Island, respectively; Evans et al. 2023), and likely will exceed the adaptive management triggers for both colony size and predation rates within two years (adaptive management triggers are based on 3-year averages).

In summary, the IMP was largely successful in meeting its narrowly defined goals and objectives at the managed Caspian tern colony sites on Goose and Crescent islands. Throughout the management period and until just recently (2022), management was successful in greatly reducing tern colony size and smolt predation rates at these two managed sites. However, there has been a significant departure from the overall basin-wide objectives of the IMP, as indicated by: (1) the relocation of nesting terns from the managed colonies on Goose and Crescent islands to nearby sites (i.e., Blalock Islands in 2015–2020 and Badger Island in 2021–2022), (2) the reestablishment of the Crescent Island tern colony in 2021–2022, and (3) strong fidelity of terns to Goose Island throughout the management

Table 2. Caspian tern colony size and average annual predation rates (95% credible intervals) on Snake River and Upper Columbia River steelhead during the pre-management and management periods at the managed colony sites on Goose Island and Crescent Island in the Columbia Plateau region. Colony sizes and predation rates are averages for the pre-management periods (2007-2013 at Goose Island, 2007-2014 at Crescent Island) and for the management periods (2014-2022 at Goose Island, 2015-2022 at Crescent Island). Data from Roby et al. (2021), Appendix B, and Evans et al. (2023).

Managed Site	Pre-management	Management	% Change
	Colony size (number of breeding pairs)		
Goose Island	386	23	94% decrease
Crescent Island	397	19	95% decrease
	Predation rate–Snake River steelhead		
Goose Island[a]	0.1%	<0.1%	Not available
Crescent Island	4.5% (4.1–5.1%)	0.2% (0.1–0.2%)	96% decrease
	Predation rate–upper Columbia River steelhead		
Goose Island	15.7% (14.1–18.9%)	1.1% (0.7–1.8%)	93% decrease
Crescent Island	2.5% (2.2–2.9%)	0.1% (0.1–0.2%)	96% decrease

[a]Predation rates on Snake River steelhead pre-management were very low due to low availability to terns nesting on Goose Island, which is at least 75 km from the Snake River.

period despite ongoing nest dissuasion activities. Consequently, the anticipated survival benefits to ESA-listed juvenile salmonids associated with Caspian tern management in the Columbia Plateau region have not been achieved, indicating the need for further adaptive management, as with the EMP.

CRITICAL UNCERTAINTIES AND NEED FOR FURTHER ADAPTIVE MANAGEMENT

Many of the stated goals and objectives of the two management plans have been met. Most notably, Caspian tern management has led to substantial localized reductions in predation rates on juvenile steelhead, the salmonid species most impacted by tern predation, at those colonies where management actions have occurred (Roby et al. 2021). Despite reductions in the size of managed tern colonies, however, terns continue to be philopatric to both managed sites and nearby prospective colony sites in the basin (e.g., Rice Island, Goose Island; Figure 6). This philopatry has resulted in significant departures from the stated objectives of both the estuary and inland management plans, as well as from the underlying intent to enhance smolt survival throughout the Columbia River basin (Roby et al. 2021; Evans et al. 2023). Nest site tenacity should be expected because the anthropogenic factors attracting Caspian terns to nest in the Columbia River basin have not changed, namely (1) an ample food supply (i.e., over 100 million hatchery-reared smolts released in the basin each year), (2) the creation of suitable tern nesting habitat associated with river management operations (e.g., dumping of dredged material on islands, predator-free islands in impoundments), and (3) the lack of suitable and persistent nesting opportunities for terns outside the basin due to the ephemeral nature of Caspian tern nesting habitat. Until one or more of these factors change, we can expect continued, perennial adaptive management to be necessary to prevent tern predation rates on ESA-listed salmonid stocks from returning to pre-management levels.

Increasingly, Caspian terns are seeking nesting opportunities within, instead of outside, the Columbia River basin, due in part to the lack of suitable nest sites outside the basin. The alternative colony sites created for terns as part of the two management plans are predominantly in inland basins that are prone to drought (Figure 6), which when coupled with other limiting factors (e.g., buildup of nest predators, vegetation encroachment), have rendered several of the alternative colony sites either devoid of nesting terns or underutilized. A remedy to this situation requires ongoing and regular (i.e., yearly) adaptive management addressing the site-specific factors limiting colony size and nesting success. The increasing frequency and intensity of drought in the SONEC region, however, is a challenge to the sustainability of these alternative colony sites even with adaptive management (Haig et al. 2019).

Despite the creation of alternative colony sites for Caspian terns outside the basin, suitable tern nesting habitat remains limiting as evidenced by the recent increase in Caspian terns nesting on warehouse rooftops, barges, parking lots, and other mainland sites that are unacceptable to property owners and/or not well-protected from mammalian nest predators (Figure 6; Roby et al. 2021). These colony sites, many of which are located along the coast of the state of Washington, are frequently disturbed by human activity, or intentionally hazed, and therefore are not suitable as long-term colony sites. To facilitate greater and sustained breeding dispersal away from the Columbia River basin, restoration of nesting habitat for Caspian terns at coastal sites, which are not affected by drought and less prone to fluctuating forage fish availability, should be considered. Past research indicates that Caspian terns nesting at coastal sites tend to be more reliant on marine forage fish as opposed to juvenile salmonids (Collis et al. 2002; Roby et al. 2002, 2021), suggesting that impacts to ESA-listed salmonids from terns nesting at restoration sites along the coast would be far less than from terns nesting on or near salmon-bearing rivers or in freshwater zones of estuaries. Caspian terns have a long history of nesting at sites along the Washington coast and are returning to this region year after year to attempt to nest in unsuitable habitat with little to no success. We recommend that managers consider providing alternative nesting sites for Caspian terns in Grays Harbor, the Strait of Juan de Fuca, and/or Puget Sound as a complement to the alternative sites already created/enhanced for terns at inland sites. These coastal regions have a history of supporting large Caspian tern colonies, have high connectivity with the Caspian tern colonies in the Columbia River basin, and likely would pose little risk to salmonid stocks of conservation concern if the colony site was not situated near the

Figure 6. Critical uncertainties and adaptive management needed as part of management plans to reduce the impacts of Caspian terns on the survival of Endangered Species Act-listed juvenile salmonids in the Columbia River basin. Photos (left to right starting in the upper left) show: (1) empty tern nest scrapes on the East Sand Island tern colony following eagle disturbance and high rates of nest predation by gulls; (2) active nest dissuasion (hazing) of terns attempting to nest on Rice Island; (3) terns attempting to nest on a warehouse rooftop on the waterfront in Seattle, Washington; (4) a dried lake bed of Crump Lake during drought, causing the Crump Lake tern island in the background to become land-bridged, accessible to mammalian predators, and unsuitable as tern nesting habitat.

mouth of a river where salmon hatcheries are located (Roby et al. 2021).

The latest estimate of the Pacific Flyway population of Caspian terns in 2021 indicates that, since tern management in the estuary began in 2008, the population has declined by more than 50% (Lawes et al. 2022). This population decline is due primarily to the dramatic decline in the size of the East Sand Island colony and the repeated nesting failures at the colony in recent years (Figure 6; see above). In 2008, the East Sand Island colony numbered over 10,000 breeding pairs and represented two-thirds of the entire Pacific Flyway breeding population (Suryan et al. 2004), while in 2022 the colony consisted of just 1,725 breeding pairs, well below the management target of 3,125–4,375 breeding pairs (Evans et al. 2023). A decline in the Pacific Flyway population of this magnitude was identified in the EMP as a trigger that would prompt adaptive management to reverse the decline and prevent putting the Caspian tern population at risk (USFWS 2006). Unfortunately, this trigger point has now been exceeded, indicating the need for adaptive management. In keeping with the EMP, adaptive management to restore the tern colony at East Sand Island to levels identified in the plan (i.e., 3,125–4,375 breeding pairs) should be considered. If the tern colony on East Sand Island continues to fail to produce any young in most years, the colony will continue to decline and would likely be abandoned within a few years. Population projection models for the Pacific Flyway population of Caspian terns indicate that if the colony on East Sand Island drops below 1,000 breeding pairs and/or produces few, if any young in most years, the population will crash to very low levels (Suzuki et al. 2018). Adding to the growing conservation concern for the Pacific Flyway population of Caspian terns is the recent emergence of highly pathogenic avian influenza, which has caused mortality of over 1,000 Caspian terns in the Pacific Flyway population, including in the Columbia River estuary, by the time of this writing (M. J. Lawonn, Oregon Department of Fish and Wildlife, personal communication).

Adaptive management actions that would halt the decline of the East Sand Island tern colony include (1) enhancing the sandy substrate on the designated tern colony site, (2) implementing limited lethal control of gulls that are nesting on the

tern colony site and depredating tern eggs and chicks, and (3) deploying resident colony monitors to dissuade bald eagles and detect other factors limiting tern colony size and nesting success. These actions, along with the establishment of a tern colony along the Washington coast, should help stabilize the Pacific Flyway Caspian tern population and draw prospecting terns away from Columbia basin sites (e.g., Rice Island and colony sites in the Columbia Plateau region) where per capita tern predation rates on smolts are known to be significantly higher than at East Sand Island. By creating a network of suitable tern nesting sites (Lu et al. 2020) along the Pacific coast that support productive and sustainable breeding colonies, the Caspian tern population in the Pacific Flyway can be conserved at its current size of about 8,000 breeding pairs, which is less than half of the peak population size recorded in 2009 (Lawes et al. 2022). Adaptive management could thereby reduce mortality of ESA-listed salmonids due to tern predation in the Columbia River basin to levels less than the objectives of the Estuary and Inland Tern Management Plans without driving down the tern population to unprecedented low levels (Gill and Mewaldt 1983).

Of all the many phases in a natural resource management program, the adaptive management phase is perhaps the most important. This is when managers can apply what they have learned from implementing management to improve outcomes and bring about lasting results (Walters 2002; Williams et al. 2009). The importance of timely adaptive management has been reinforced in recent years with the reversal in smolt survival gains associated with tern management due to delayed, ineffective, or deferred adaptive management both within and outside the basin. Addressing these critical uncertainties with perennial adaptive management is necessary if the full benefits of managing Caspian terns to improve survival of ESA-listed juvenile salmonids in the Columbia River basin are to be realized without forcing the Pacific Flyway population of Caspian terns to very low levels.

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