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EFFECTS OF COLONY RELOCATION ON DIET AND PRODUCTIVITY OF CASPIAN TERNS

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Abstract: We investigated the efficacy of management to reduce the impact of Caspian tern (*Sterna caspia*) predation on survival of juvenile salmonids (*Oncorhynchus* spp.) in the Columbia River estuary. Resource managers sought to relocate approximately 9,000 pairs of terns nesting on Rice Island (river km 34) to East Sand Island (river km 8), where terns were expected to prey on fewer juvenile salmonids. Efforts to attract terns to nest on East Sand Island included creation of nesting habitat, use of social attraction techniques, and predator control, with concurrent efforts to discourage terns from nesting on Rice Island. This approach was successful in completely relocating the tern colony from Rice Island to East Sand Island by the third breeding season. Juvenile salmonids decreased and marine forage fishes (i.e., herring, sardine, anchovy, smelt, surfperch, Pacific sand lance) increased in the diet of Caspian terns nesting on East Sand Island, compared with terns nesting on Rice Island. During 1999 and 2000, the diet of terns nesting on Rice Island consisted of 77% and 90% juvenile salmonids, respectively, while during 1999, 2000, and 2001, the diet of terns nesting on East Sand Island consisted of 46%, 47%, and 33% juvenile salmonids, respectively. Nesting success of Caspian terns was consistently and substantially higher on East Sand Island than on Rice Island. These results indicate that relocating the Caspian tern colony was an effective management action for reducing predation on juvenile salmonids without harm to the population of breeding terns, at least in the short term. The success of this management approach largely was a consequence of the nesting and foraging ecology of Caspian terns: the species shifts breeding colony sites frequently in response to changing habitats, and the species is a generalist forager, preying on the most available forage fish near the colony.

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We conducted a comprehensive study of the diet composition of piscivorous (fish-eating) colonial waterbirds (several gull species [*Larus* spp.], Caspian terns, and double-crested cormorants [*Phalacrocorax auritus*]) nesting at colonies in the lower Columbia River during 1997 and 1998 (Collis et al. 2002*a*). The study was prompted by concern from salmon fishery managers that the magnitude of avian predation on juvenile salmonids in the lower Columbia River might be sufficient to inhibit recovery of some Columbia Basin stocks that are listed as endangered or threatened under the U.S. Endangered Species Act. Our results indicated that of the above species of piscivorous waterbirds, Caspian terns relied most on juvenile salmonids as a food source, which constituted 73–81% of their diet (Collis et al. 2002*a*).

Of particular concern was the impact of the large Rice Island Caspian tern colony on survival of juvenile salmonids in the Columbia River estuary. Rice Island, a large dredge spoil island at river km 34 in the estuary, was home to the largest Caspian tern colony in North America (Cuthbert and Wires 1999), and perhaps in the world. Preliminary estimates of the number of juvenile sal-

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monids consumed by terns nesting on Rice Island were in the millions (Roby et al. 1998, Collis et al. 1999), many of which are from 12 evolutionarily significant units (ESUs) that are listed under the Endangered Species Act (Collis et al. 2001). Analysis of Passive Integrated Transponder (PIT) tags recovered from the Rice Island Caspian tern colony indicated that a minimum of 13% of steelhead smolts (*O. mykiss*), 4% of coho salmon smolts (*O. kisutch*), and 2% of spring–summer chinook salmon smolts (*O. tshawytscha*) that reached the estuary in 1998 were consumed by Caspian terns nesting on Rice Island (Collis et al. 2001). Consequently, regional resource managers (National Marine Fisheries Service, U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, Oregon Department of Fish and Wildlife, Washington Department of Fish and Wildlife, Idaho Department of Fish and Game, Columbia River Inter-Tribal Fish Commission, and others) formed the Caspian Tern Working Group in 1998. The Working Group considered a number of management alternatives aimed at reducing the impacts of Caspian tern predation on survival of juvenile salmonids in the Columbia River estuary, as part of comprehensive plans to restore salmonids throughout the Columbia River Basin.

Several management approaches to reduce avian predation on fish stocks of special concern have been attempted previously (Thomas 1972, Draulans 1987, Dolbeer et al. 1996). These techniques include (1) lethal control of adult birds (Elson 1962, Bédard et al. 1995); (2) limiting the productivity of fish-eating birds (Morris and Siderius 1990, Christens and Blokpoel 1991, Pochop et al. 1998); (3) hazing fish-eating birds in areas where they nest or forage (Bayer 1989, Schaeffer 1992); (4) protecting fish in areas where they are vulnerable to bird predation (Ostergaard 1981, Blokpoel and Tessier 1984, Steuber et al. 1995); and (5) changing rearing practices in hatcheries to produce more viable and predator-wary fish (Suboski and Templeton 1989, Olla et al. 1990, Wiley et al. 1993, Berejikian 1995). Some of these practices already have been implemented in the Columbia River Basin; hazing and passive exclusion of fish-eating birds near dams and hatcheries are now widespread (Jones et al. 1996). Changes to hatchery practices are being investigated and implemented (the Natural Rearing Enhancement System or NATURES program) to increase post-release survival of hatchery-raised juvenile salmonids from the Columbia River Basin (Maynard et al. 1995, 1996). On a more local scale, lethal control of adult birds and oiling of eggs at nesting colonies have been implemented at some sites in the mid-Columbia River by U.S. Department of Agriculture-Wildlife Services (Pochop et al. 1998). Many of these approaches show great promise in reducing avian predation on juvenile salmonids. However, destructive techniques continue to be controversial because they are unacceptable to some publics, and they are contrary to the spirit of the Migratory Bird Treaty Act.

Diet studies conducted in 1997 and 1998 (Collis et al. 2002*a*) lent support to another potential method for reducing conflicts between Caspian terns and at-risk salmonid populations in the Columbia Basin, namely to relocate the Rice Island tern colony. The diet composition of double-crested cormorants and glaucous-winged–western gulls (*L. glaucescens* × *L. occidentalis*) nesting on Rice Island and on East Sand Island suggested that if the terns nested on East Sand Island instead of Rice Island they might consume fewer juvenile salmonids and more marine forage fishes (Collis et al. 2002*a*). In addition to the significantly lower proportion of salmonids in the diets of cormorants and gulls nesting on East Sand Island, Caspian terns returning to the Rice Island colony from foraging locations downriver had consumed fewer juvenile salmonids compared with terns returning from foraging locations upriver (Collis et al. 2002*a*).

The potential efficacy of relocating the Rice Island Caspian tern colony to East Sand Island was based on the following premises: (1) suitable nesting habitat for Caspian terns could be provided at East Sand Island; (2) terns could be attracted to nest at the new colony site; (3) relocation of nesting terns would lead to significant changes in their foraging distribution and diet composition; and (4) terns could nest successfully at East Sand Island, so that breeding pairs would tend to return to the new site in subsequent years. Recent restoration of tern breeding colonies both in the Gulf of Maine (Kress 1983, 1998) and in the Great Lakes region (Lampman et al. 1996, Quinn et al. 1996) suggested that a Caspian tern breeding colony could be restored on East Sand Island, where Caspian terns had nested during 1984–1986. Historical breeding colonies of common, arctic, and roseate terns (*Sterna hirundo, S. paradisaea,* and *S. dougallii,* respectively) have been successfully restored along the coasts of Massachusetts, New Hampshire, Maine, and New Brunswick (Kress 1983, 1998), and new Caspian tern colonies have been established on artificial islands in Lake Ontario

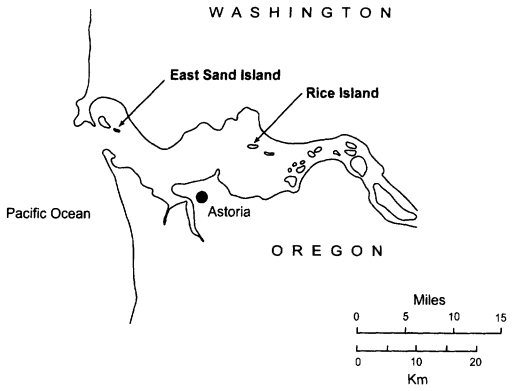

Fig. 1. Columbia River estuary showing locations of Rice Island and East Sand Island, 2 sites that have supported Caspian tern nesting colonies in the estuary.

(Lampman et al. 1996, Quinn et al. 1996). These studies employed a combination of habitat enhancement, social attraction using decoys and audio playbacks of vocalizations, limited gull control, and continuous monitoring of newly restored tern colonies to establish and maintain colonies at sites where tern nesting had never before been recorded or had not occurred for decades (Kress 1983). Although these studies did not attempt to relocate tern breeding colonies from 1 site to another, colony restoration techniques used at East Sand Island, in conjunction with methods to discourage nesting by Caspian terns at Rice Island, might be effective in relocating the Rice Island colony to East Sand Island.

Our objectives in this study were to monitor and evaluate the efforts of resource management agencies to relocate the Caspian tern colony from Rice Island to East Sand Island and to test the efficacy of this approach for reducing the reliance of terns on juvenile salmonids as a food source. Presented here are results that compare the colony size, diet composition, and productivity of Caspian terns nesting on Rice and East Sand islands during 1999–2001. These types of data also were collected at the Rice Island colony during 1997 and 1998, prior to the initiation of Caspian tern management in the Columbia River estuary. Data on colony size and productivity in those 2 years are presented here, while data on diet composition are presented elsewhere (Collis et al. 2002*a*).

STUDY AREA

We estimated breeding colony size, diet composition, and productivity of Caspian terns nesting on Rice Island (46°14′58″N, 123°42′56″W) and East Sand Island (46°15′45″N, 123°58′06″W) in the Columbia River estuary (Fig. 1) to evaluate management initiatives implemented to reduce the impact of tern predation on the survival of juvenile salmonids from throughout the Columbia River Basin. As part of their management plan, resource managers sought to relocate terns nesting at the western tip of Rice Island to newly restored tern nesting habitat on the eastern tip of East Sand Island, where nesting terns were expected to rely less on juvenile salmonids as a food source due to the proximity of the latter island to the ocean (Fig. 1). Rice Island is completely artificial and was first created from disposal of dredged materials in 1962; today, it consists of approximately 100 ha of mostly bare sand habitat. East Sand Island is a natural island of approximately 25 ha that has been greatly modified by human activities, and several hectares at the east end of the island were used as a dredged material disposal site in 1983 (USACE 2001).

METHODS

Colony Site Preparation

East Sand Island.—In March 1999, bulldozers were used to prepare bare sand nesting habitat at the extreme east end of East Sand Island by clearing woody debris, removing vegetation, and grading the sandy dredge spoil prior to the arrival of breeding Caspian terns in the Columbia River estuary in 1999. The intended colony site had been used as a dredged material disposal site when the Chinook Channel was dredged in 1983 (USACE 2001), and Caspian terns formerly nested on or near the site during 1984–1986. Following the bulldozer work, tractors were used to smooth the surface and fill in depressions, creating about 3.0 ha of bare sand habitat, similar to the amount of bare sand habitat available at the Rice Island colony site in 1998. Sandy dredged material was in limited supply on the site, however, so approximately half this area had only a thin covering of sandy soil and encroachment by vegetation was rapid.

We installed 380 Caspian tern decoys (Mad River Decoys, Waitsfield, Vermont, USA) and 4 audio playback systems (Murre Maid Music Boxes, South Bristol, Maine, USA) in the center of the bare sand area on East Sand Island. The audio systems broadcast digital recordings of Caspian tern calls that had been recorded at the Rice Island colony (Alaska's Spirit Speaks, Fairbanks, Alaska, USA).

The decoys and audio systems were intended to provide social attraction and encourage prospecting terns to settle and nest on the newly restored habitat on East Sand Island (see Kress 1983 for full description of social attraction methods). In addition, we used firearms (.22 caliber Long Rifle) to selectively remove a limited number of glaucous-winged–western gulls from the newly restored tern colony site to enhance prospects for successful restoration of a tern colony on East Sand Island. East Sand Island is the site of the second largest breeding colony of glaucous-winged–western gulls on the West Coast of the United States, consisting of about 7,000 breeding pairs (Collis et al. 2002*a*). Nest predation by glaucous-winged–western gulls was the primary cause of Caspian tern nest failure on the Rice Island colony (Roby et al. 1998). Consequently, gull predation was considered a high risk factor for restoration of a Caspian tern colony on East Sand Island.

By early 2000, vegetation had encroached on a large portion of the East Sand Island colony area that had been cleared the previous year. In March 2000, tractors were used to till the colony area and uprooted plants were removed by hand, re-creating about 1.6 ha of bare sand habitat prior to the arrival of nesting terns—an area agreed on by the Caspian Tern Working Group. We placed 415 tern decoys and 4 audio playback systems in the middle of the cleared habitat to again attract terns to nest at the site. As in 1999, limited gull control was conducted at the East Sand Island tern colony to enhance the prospects for successful tern nesting.

During 2001, vegetation encroaching on the 1.6-ha East Sand Island colony site (mostly European beach grass [*Ammophila arenaria*]) was treated with an herbicide (6.5 l of Rodeo) in mid-March, prior to the tillage and hand removal of uprooted plants later that month. About 1.5 ha of bare sand habitat was prepared on East Sand Island during 2001. In addition, 2 20- to 30-m-wide buffer strips were prepared on either end of the core colony area. These buffer strips were cleared of vegetation by scarifying the surface, but no deep tillage was conducted to remove rhizomes or roots of scarified plants. These buffer strips were intended to discourage nesting by glaucous-winged–western gulls (which prefer vegetated nesting habitat) and thus provide nesting terns with protection from gulls that previously used these areas. We placed 253 tern decoys and 2 audio playback systems in the center of the cleared habitat on East Sand Island prior to the arrival of terns at the site. The Caspian Tern Working Group decided not to continue with gull control at the East Sand Island tern colony in 2001.

Rice Island.—In 1999, the area of suitable habitat previously used by nesting terns on Rice Island (approximately 3.0 ha) was reduced prior to the return of Caspian terns to the Columbia River estuary. Because Caspian terns prefer open, unvegetated patches of bare sand for nesting (Quinn and Sirdevan 1998), suitable nesting habitat on Rice Island was reduced by planting winter wheat (*Triticum aestivum*), erecting vertical silt fencing, and stringing wire and streamers across the previous colony site. An area of 0.65 ha in the core of the colony site was left unaltered, and terns attempting to nest there were not disturbed at any time during the 1999 breeding season. Winter wheat was planted in late February on the remainder of the Rice Island colony area, as well as in all other unvegetated dredge spoil that had not been previously used for tern nesting on Rice Island and other upper estuary islands (i.e., Miller Sands Spit [46°14′44″N, 123°40′51″W] and Pillar Rock Sands [46°14′50″N, 123°40′10″W]). Once it was determined that the wheat planted on the Rice Island colony site would not be fully established by the time terns initiated nesting (due to a cold and wet spring that inhibited seed germination and growth), silt fencing was erected in rows at 4.5-m intervals on the portion of the colony area that was planted with wheat. After the arrival of terns to the breeding grounds and prior to egg laying, limited hazing of terns using bald eagle decoys and human harassment were conducted to discourage nesting in off-colony areas where terns had not previously nested.

During spring 2000, a thick mat of planted and weedy vegetation had developed on the portion of the former tern colony where silt fencing had been erected in the previous year. The silt fencing, which was left in place after the 1999 breeding season, evidently helped trap plant seeds on the colony. The silt fencing that had been installed the previous year was repaired and streamers (i.e., colored bailing twine fixed to rebar posts with orange flagging tied along the twine at 1.5-m intervals) were used in areas without fencing or vegetation to reduce the suitable tern nesting habitat on the colony site from 0.65 ha in 1999 to 0.2 ha in 2000. Due to a temporary restraining order (U.S. District Court, Western Washington, 2000), no hazing or harassment of Caspian terns were conducted at Rice Island in 2000.

By early spring 2001, weedy vegetation had further encroached on the tern colony area on Rice

Island. Silt fencing was repaired and streamers were placed in all other areas without fencing or vegetation to eliminate all available tern nesting habitat on the former tern colony site. As in the previous year, no deliberate hazing of terns to discourage nesting was conducted on Rice Island in 2001, due to continued litigation.

Data Collection and Analysis

Field camps were set up on Rice and East Sand islands so that tern colonies could be monitored throughout the breeding season by field biologists. We constructed observation blinds at the periphery of each tern colony to facilitate colony observations without disturbing nesting terns. Data on number of terns on the colony, diet composition, and causes of tern nesting failure were collected daily.

Colony Size and Productivity.—Numbers of Caspian terns breeding in the Columbia River estuary in each year of the study were estimated using aerial photographs taken of the Rice Island and East Sand Island colonies near the end of the incubation period. An average of 2 direct counts from aerial photos of all adult terns on the colony was corrected to estimate the number of breeding pairs at each colony using simultaneous counts from the blinds of the numbers of incubating and nonincubating terns on plots. Productivity (number of young raised to fledging age per breeding pair) at the Rice and East Sand island tern colonies was estimated using ground counts or aerial photos taken of the colony just prior to the fledging period. An average of 2 direct counts from the photos of all terns (adults and juveniles) on the colony was corrected to estimate the number of fledglings on the colony using simultaneous counts from the blinds of adults and fledglings on plots. Further details of the aerial photo census methods used in this study are described in Collis et al. 2002*a*.

Diet Composition.—Terns transport whole fish in their bills to their mates (courtship meals) and young (chick meals). Therefore, with the aid of binoculars and spotting scopes, taxonomic composition of the diet was determined by direct observation of adults as they returned to the colony with fish (bill-load observations). The target sample size was 350 bill-load identifications per week at each colony. Observations to identify bill loads were conducted concurrently at the Rice Island and East Sand Island tern colonies twice each day, once each at high and low tide to control for potential tidal and time of day effects on diet. Prey items were identified to the lowest distinguishable taxa. We were confident of our ability to distinguish salmonids from nonsalmonids and to distinguish most nonsalmonid taxa based on direct observations from blinds, but we did not attempt to differentiate between the various salmonid species.

To assess the relative proportion of the various salmonid species in tern diets, we collected approximately 10 bill-load fish/week at each tern colony by shooting Caspian terns returning to the colonies with whole fish carried in their bills (referred to hereafter as bill-load collections). We collected tern bill loads at Rice Island in 1999 and 2000 only (no terns nested on Rice Island in 2001). We collected tern bill loads at East Sand Island in 2000 and 2001 only (no terns were collected at the newly restored tern colony in 1999). Bill loads were collected throughout the breeding season from late April through July, with the exception of July 2000 at Rice Island and April 2001 at East Sand Island. Bill-load collections were curtailed at Rice Island in late June 2000 because of the potential impact of our sampling on a small colony. Bill-load collections at East Sand Island in April 2001 were precluded by delays in the issuance of a federal scientific collecting permit.

Salmonids collected as bill-load samples were identified as chinook salmon, sockeye salmon (*O. nerka*), coho salmon, steelhead, or unknown based on soft tissue or otolith analysis. Chinook salmon were further separated into fall (sub-yearlings) and spring–summer (yearling) stocks using fork length and migration timing information (see Dawley et al. 1985). The species composition of salmonids in bill-load samples did not differ between years at either Rice Island in 1999 and 2000 ($\chi^2 = 5.33$, $P = 0.15$) or East Sand Island in 2000 and 2001 ($\chi^2 = 5.75$, $P = 0.12$), and therefore were pooled among years to increase sample sizes. Further details on the methods used to analyze bill-load observations and collected diet samples are presented in Collis et al. (2002*a*).

Chi-square tests for independence (χ^2) were used for all statistical comparisons of diet composition. Means are expressed as $\bar{x} \pm$ SE. Significance was determined at $P \leq 0.05$ for all tests.

RESULTS

Tern Colony Size

All nesting Caspian terns shifted from the colony site on Rice Island to the restored site on East Sand Island during the 3-year period 1999–2001, when Caspian terns were actively managed in the Columbia River estuary (Fig. 2a). Habitat restora-

tion, social attraction, and gull control at the East Sand Island colony site were successful in attracting terns to breed there in 1999 and provided suitable nesting habitat for terns that formerly nested on Rice Island (Fig. 2b). Efforts to reduce available nesting habitat on Rice Island were successful in reducing the area used by nesting terns (Fig. 2b). The number of terns nesting on Rice Island increased in 1998, while total numbers of nesting terns in the Columbia River estuary remained approximately stable during 1999–2001 (Fig. 2a).

In 1999, about 550 pairs of Caspian terns were nesting at the restored colony site on East Sand Island at the time of the aerial photo census in late May, or about 6% of the total number of breeding pairs in the Columbia River estuary (Fig. 2a). By early July, when the pre-fledging photo census was conducted, the East Sand Island tern colony had more than doubled to 1,400 breeding pairs that occupied 0.3 ha of the available habitat (Fig. 2b). Tern nesting density in this newly established colony where suitable nesting habitat far exceeded demand was 0.26 nests/m^2 (Fig. 3a). In 1999, the Rice Island Caspian tern colony consisted of about 8,300 nesting pairs, or about 350 fewer pairs than nested on the colony the previous year (Fig. 2a). The area used by nesting terns on Rice Island declined from 2.0 ha in 1998, prior to tern habitat management, to 1.1 ha in 1999 (Fig. 2b). In 1999, nesting Caspian terns completely filled the 0.7-ha core area of habitat intended for tern nesting, and also nested on 2 new sites just outside the former colony site; these 2 new satellite colonies together occupied an area of 0.4 ha. Terns nesting on Rice Island in 1999 compensated for the reduction in area of nesting habitat by nesting at higher densities than previously (0.78 nests/m^2 in 1999 vs. 0.44 nests/m^2 in 1998; Fig. 3a).

In 2000, 94% of the Caspian terns that nested in the Columbia River estuary were on East Sand Island (Fig. 2a). At the time of the photo census in late May, approximately 8,500 breeding pairs were on East Sand Island and only about 590 pairs were nesting on Rice Island (Fig. 2a). The East Sand Island tern colony occupied 1.4 ha, or most of the 1.6 ha of available habitat (Fig. 2b), and the nesting density increased to 0.62 nests/m^2 (Fig. 3a). The area of suitable tern nesting habitat left on Rice Island in 2000 (0.2 ha) was less than in the previous year (1.1 ha). Nesting density at Rice Island in 2000 was only 0.25 nests/m^2, compared with 0.78 nests/m^2 in 1999 (Fig. 3a).

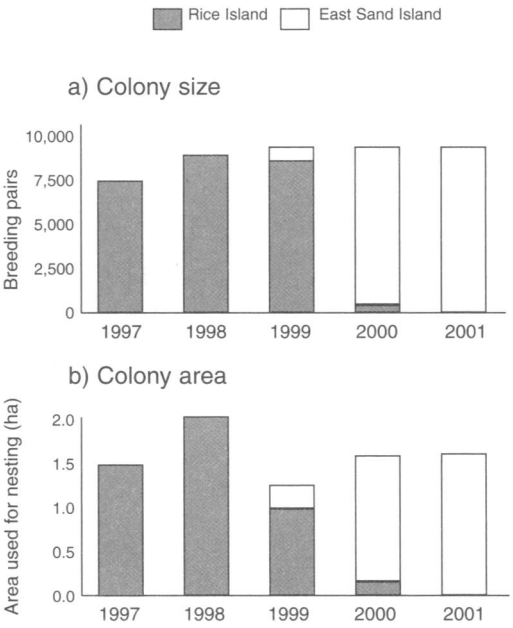

Fig. 2. Estimates of the number of breeding pairs of Caspian terns at colonies on Rice Island and East Sand Island in the Columbia River estuary (a) and area used by nesting terns at each colony (b) during 1997–2001. The number of breeding pairs on Rice Island and the area used for nesting during 1997–1998, prior to tern management in the estuary, are presented as a baseline but are not presented in the text. All values are derived from high-resolution, low-altitude aerial photographs of the colonies (see text).

In 2001, all nesting by Caspian terns in the Columbia River estuary occurred on East Sand Island (Fig. 2a). Approximately 8,900 pairs were nesting on the colony at the time of the photo census in late May. Early in the 2001 breeding season (Apr and May), terns were occasionally seen roosting on bare sand dredge spoil directly east of the old colony site on Rice Island. One Caspian tern egg was laid in this area, but it was depredated by gulls the following day. No other tern nesting attempts were detected on Rice Island in 2001. In 2001, terns nesting on East Sand Island occupied about 1.6 ha of habitat, including all 1.5 ha of quality tern nesting habitat prepared for them prior to the nesting season, plus about 0.1 ha in 1 of the 2 buffer strips provided at either end of the colony site. Nesting density in 2001 was 0.57 nests/m^2, intermediate between nesting densities at East Sand Island in 1999 and 2000 (Fig. 3a).

Tern Productivity

Productivity was consistently higher for Caspian terns nesting on East Sand Island compared with

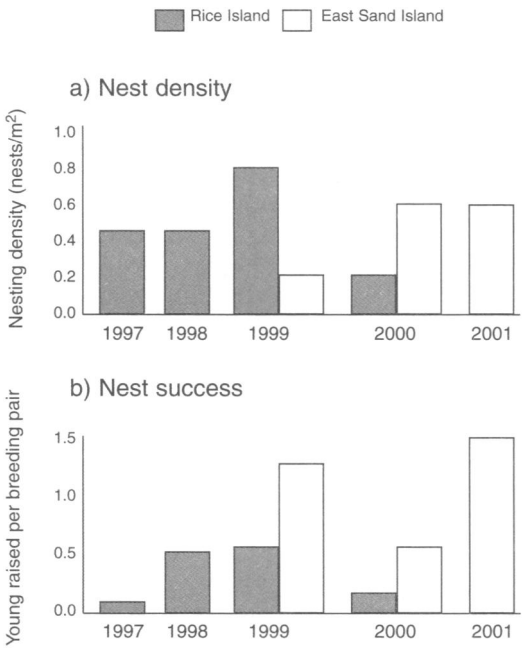

Fig. 3. Estimates of nesting density (a) and nesting success (b) for Caspian terns nesting at colonies on Rice Island and East Sand Island in the Columbia River estuary during 1997–2001. The nesting density and nesting success on Rice Island during 1997–1998, prior to tern management in the estuary, are presented as a baseline but are not presented in the text. All values are derived from high-resolution, low-altitude aerial photographs of the colonies (see text).

terns nesting on Rice Island (Fig. 3b). Terns nesting on East Sand Island had higher nesting success in 1999 and 2000, the 2 years when terns nested on both Rice Island and East Sand Island.

In 1999, we estimated that about 4,600 and 1,680 young terns were fledged from the Rice Island and East Sand Island colonies, respectively. Caspian tern nesting success on the Rice Island colony in 1999 was about 0.55 young raised per breeding pair, slightly higher productivity than at the colony in 1998 (0.45 young raised per breeding pair), prior to initiation of tern management (Fig. 3b). In comparison, nesting success at East Sand Island in 1999 was approximately 1.20 young raised per breeding pair (Fig. 3b). The removal of 183 glaucous-winged–western gulls from the tern colony site was at least partly responsible for high tern nesting success at East Sand Island compared with Rice Island in 1999.

In 2000, we estimated that only about 90 young terns were fledged from the Rice Island colony and approximately 4,800 young terns were fledged at the East Sand Island colony. This corresponds to productivity of 0.15 and 0.57 young raised per breeding pair at Rice Island and East Sand Island, respectively (Fig. 3b). Only 40 glaucous-winged–western gulls were shot at the East Sand Island colony in 2000, compared with 183 in the previous year, because gull predation rates on tern eggs and chicks were considerably lower than in 1999. The reduction in nesting success at East Sand Island in 2000 compared with 1999 was partly due to a severe wind and rain storm that hit the island soon after hatching and caused the deaths of about 1,000 tern chicks.

In 2001, productivity at the East Sand Island tern colony was about 12,500 young terns fledged, or about 1.40 young raised per breeding pair, the highest productivity that we observed at either Caspian tern colony in the Columbia River estuary after 1996 (Fig. 3b). This high nesting success occurred despite the absence of gull control at the East Sand Island tern colony in 2001.

Diet Composition

As we hypothesized, juvenile salmonids were less prevalent and marine forage fishes (i.e., Pacific herring [*Clupea pallasi*], Pacific sardine [*Sardinops sagax*], anchovies [Engraulidae], smelt [Osmeridae], surfperch [Embiotocidae], Pacific sand lance [*Ammodytes hexapterus*]) were more prevalent in the diets of Caspian terns nesting on East Sand Island, compared with terns nesting on Rice Island (Table 1). During the 3 years of this study, Caspian terns nesting on East Sand Island had an average of 42% salmonids in their diet, compared with an average of 83% juvenile salmonids in the diet of terns nesting on Rice Island (Table 1). In general, juvenile salmonids were most prevalent in the diets of Caspian terns nesting in the Columbia River estuary during April and May, and salmonids declined in the diet during June and July (Fig. 4). The 1 exception to this trend was at Rice Island in 2000, when the salmonid portion of the diet remained high (over 80%) for the entire breeding season (Fig. 4). Based on bill load collections, fall chinook salmon and coho salmon were the most prevalent prey types among the salmonids in the diet of terns nesting on Rice Island and East Sand Island (Table 2). On a biomass basis, fall chinook salmon were the most prevalent prey type among the salmonids in the diet of terns nesting on Rice Island, while coho salmon were the most prevalent salmonid prey type in the diet of terns nesting on East Sand Island (Table 2). However, steelhead and spring–

Table 1. Diet composition (percent identifiable prey items) of Caspian terns nesting on Rice Island (Columbia River km 34) and East Sand Island (Columbia River km 8) based on visually identified bill loads during Apr–Jul 1999–2001.

	1999		2000		2001
Prey type	Rice Island	East Sand Island	Rice Island	East Sand Island	East Sand Island
Herring, sardine, shad[a]	1.8	8.2	1.7	10.1	20.3
Anchovy[b]	6.5	15.9	0.5	11.6	22.4
Peamouth, pike minnow[c]	1.0	0.5	0.9	0.8	0.6
Smelt[d]	0.9	3.8	0.7	5.6	5.1
Salmonid[e]	76.5	45.6	89.6	46.5	32.5
Cod[f]	0.0	0.0	0.0	0.0	2.2
Sculpin[g]	1.3	3.3	1.9	5.1	3.6
Surfperch[h]	2.8	10.7	1.2	10.0	5.9
Pacific sand lance[i]	0.1	5.9	0.1	5.6	3.1
Flounder[j]	0.3	0.2	1.8	0.6	0.2
Other[k]	8.7	5.8	1.6	3.9	3.9
Total number of prey	5,305	5,486	5,023	5,387	6,007

[a] Clupeidae.
[b] Engraulidae.
[c] Cyprinidae.
[d] Osmeridae.
[e] *Oncorhynchus* spp.
[f] Gadidae.
[g] Cottidae.
[h] Embiotocidae.
[i] *Ammodytes hexapterus.*
[j] Pleuronectidae.
[k] Lamprey (*Lampetra* spp.), stickleback (Gasterosteidae), sucker (*Catostomus* spp.), or unidentified nonsalmonids.

summer chinook salmon also constituted a significant proportion of Caspian tern diets at both colonies in the estuary (Table 2).

In 1999, the proportion of juvenile salmonids in the diet of Caspian terns nesting at the East Sand Island colony was 46%, significantly lower than the 77% juvenile salmonids in the diet of terns nesting at the Rice Island colony (χ^2 = 1,079.5, $P < 0.001$; Table 1). Anchovies were the most prevalent nonsalmonid prey type identified in the diets of terns nesting on Rice and East Sand islands in 1999 (Table 1).

In 2000, the proportion of juvenile salmonids in the diet of Caspian terns nesting at the East Sand Island colony was 47%, again, significantly lower than the 90% juvenile salmonids in the diet of terns nesting at the Rice Island colony (χ^2 = 2,194.8, $P < 0.001$; Table 1). Anchovy, clupeids, and surfperch were the most prevalent nonsalmonids in the diet of terns on East Sand Island, while sculpin, flounder, and clupeids were the most prevalent nonsalmonid prey types in the diet of terns nesting on Rice Island (Table 1).

In 2001, the proportion of juvenile salmonids in the diet of Caspian terns nesting at the East Sand Island colony was 33%, significantly lower than the 46% juvenile salmonids in the diet of terns nesting at East Sand Island in 1999 (χ^2 = 207.7, $P < 0.001$) or the 47% salmonids in 2000 (χ^2 = 233.9, $P < 0.001$; Table 1). Anchovy, herring, and sardines were the most prevalent nonsalmonid prey types in the diet of terns nesting on East Sand Island in 2001.

DISCUSSION

Caspian terns that nested on Rice Island were successfully relocated to newly restored habitat on East Sand Island over a 3-year period. This move can be attributed to concurrent management efforts to both attract terns to nest on East Sand Island (i.e., removal of vegetation, social attraction, gull control) and discourage terns from nesting on Rice Island (i.e., re-vegetation, silt fencing, streamers, eagle decoys, active harassment). Research activities conducted prior to initiation of nesting in 2000 may have contributed to movement of some nesting terns from Rice Island to East Sand Island. We used rocket nets to capture nearly 600 adult terns on the Rice Island colony for banding in mid-April. The disturbance associated with this research may have induced some adult terns to abandon Rice Island as a breeding site and shift to East Sand Island (Blokpoel 1981). However, no deliberate hazing of terns to discourage nesting was conducted on Rice Island during 2000 or 2001.

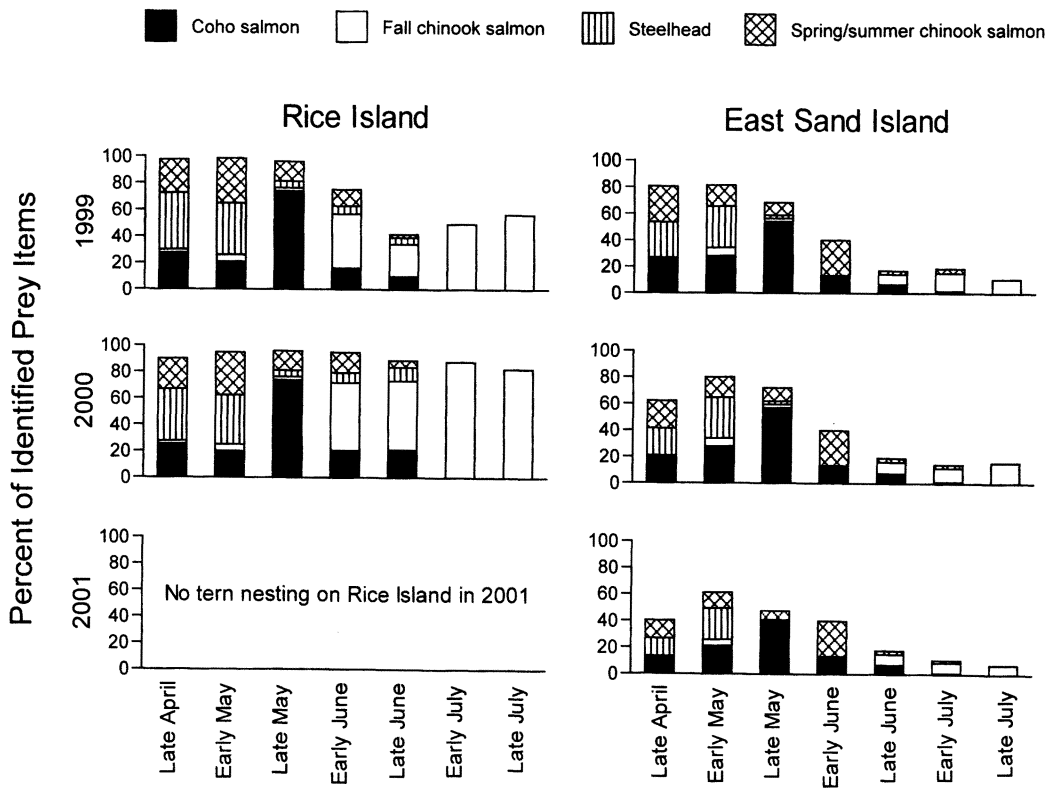

Fig. 4. Taxonomic composition of the salmonid portion of the diet of Caspian terns nesting on Rice Island and East Sand Island during 7 stages of the 1999, 2000, and 2001 breeding seasons. The overall proportion of salmonids in the diet was based on visual identification of bill load fish at each colony in each of the 3 years of study (see text for sample sizes). The proportions of the various salmonid stocks in the salmonid portion of the diet were based on bill load fish collected at Rice Island in 1999 and 2000 (n = 200) and East Sand Island in 2000 and 2001 (n = 111); bill load samples were combined by year but separated by colony.

The successful restoration of the East Sand Island Caspian tern colony is partly a reflection of the nesting ecology of this species. Caspian terns prefer to nest on patches of open habitat covered with sand (Quinn and Sirdevan 1998), at a safe elevation above the high tide line, and on islands that are devoid of mammalian predators (Cuthbert and Wires 1999). These habitats typically are ephemeral, and can be created or destroyed during winter storm events. Breeding Caspian terns must adapt to these changes in available nesting habitat. Consequently, Caspian terns are preadapted to shifting their nesting activities from 1 site to another more so than most other colonial seabirds (Cuthbert 1988, Cuthbert and Wires 1999).

The diet composition of Caspian terns nesting on Rice and East Sand islands suggests that relocating the tern colony to East Sand Island significantly enhanced survival of juvenile salmonids in the estuary. As predicted, juvenile salmonids were less prevalent and marine forage fishes more prevalent in the diets of Caspian terns nesting on

Table 2. Taxonomic composition of the salmonid portion of the diet of Caspian terns nesting on Rice Island (Columbia River km 34) during 1999 and 2000 and on East Sand Island (Columbia River km 8) during 2000 and 2001, based on the composition of bill load fish collected from breeding adults during late Apr–Jul.

	Rice Island		East Sand Island	
Salmonid stock	% Mass	% No.	% Mass	% No.
Coho salmon	23.8	24.5	32.9	32.8
Steelhead	25.9	15.4	16.3	10.7
Fall chinook salmon	37.8	46.2	25.9	32.7
Spring–summer chinook salmon	12.6	13.9	24.8	23.7
Total mass (g) and number of salmonids	6,563	200	3,641	111

East Sand Island compared with terns nesting on Rice Island. Juvenile salmonids constituted 77% and 90% of the diet of terns nesting on Rice Island during 1999 and 2000, respectively, compared with 46%, 47%, and 33% of the diet of terns nesting on East Sand Island during 1999, 2000, and 2001, respectively. Thus, Caspian terns nesting on Rice Island during 1999 and 2000 continued to be highly reliant on juvenile salmonids as a food source, as they were during 1997 and 1998 (Collis et al. 2001, 2002*a*), perhaps due to a paucity of alternative forage fish near Rice Island (Hinton et al. 1995). The differences in the proportion of salmonids in the diets of Caspian terns nesting on Rice and East Sand islands also are consistent with the significant intercolony differences in the diets of other piscivorous waterbirds (i.e., cormorants, gulls) nesting on the 2 islands (Collis et al. 2002*a*). The major differences in diet composition of Caspian terns nesting at colonies only 21 km apart suggest that the terns foraged primarily in close proximity to their nesting colony, instead of commuting longer distances to favored foraging sites.

Our results also indicate that relocating the tern colony to East Sand Island enhanced the productivity of Caspian terns nesting in the Columbia River estuary. Nesting success of Caspian terns on East Sand Island (0.57–1.40 young raised per breeding pair) was consistently higher than for terns on Rice Island, both prior to tern management (1997–1998: 0.06–0.45 young raised per breeding pair) and post-management (1999–2000: 0.15–0.55 young raised per breeding pair). The productivity measured at Rice Island was considerably lower than at other well-studied Caspian tern colonies in North America (range of 0.6–1.6 young raised per breeding pair; Cuthbert and Wires 1999). Nesting success at Rice Island during 1997–2000 may not have been adequate to compensate for annual adult and subadult mortality. Nesting density, which ranged from 0.25 to 0.78 nests/m^2 on Rice Island, and from 0.26 to 0.62 nests/m^2 on East Sand Island, was not apparently related to nesting success at either colony (Figs. 3a,b). Low productivity at the Rice Island colony during 1997 and 1998 may have been a factor contributing to the lack of growth in numbers of Caspian terns nesting in the Columbia River estuary in 2000 and 2001. Caspian terns do not breed for the first time until they are 3–4 years old (Cuthbert and Wires 1999), providing a plausible explanation for the paucity of new recruits to the East Sand Island colony in 2000 and 2001.

Gull control on the East Sand Island tern colony may have been largely responsible for differences in productivity between the 2 colonies during 1999 and 2000; however, in 2001, when there was no gull control on the East Sand Island tern colony, tern nesting success was the highest ever recorded in the Columbia River estuary. The high nesting success of Caspian terns on East Sand Island in 2001 was reflected in similarly high productivity among double-crested cormorants and glaucous-winged–western gulls nesting on East Sand Island (D. D. Roby, unpublished data). These piscivorous colonial waterbirds all benefited from strong coastal up-welling and associated high primary and secondary productivity along the coast of the Pacific Northwest in 2001 (R. Emmett, National Marine Fisheries Service, personal communication).

The short-term advantages to both juvenile salmonids and Caspian terns associated with the relocation of nesting terns from Rice Island to East Sand Island are evident. There may be risks, however, associated with the continued concentration of such a large number of breeding Caspian terns at a single colony site. Large proportions of the Pacific Coast population (approx. 67%), the continent-wide metapopulation (approx. 25%), and the worldwide numbers of Caspian terns (approx. 10%) continue to nest at 1 location in the Columbia River estuary (Cuthbert and Wires 1999, Wires and Cuthbert 2000). Under current conditions, the risks from disease, storms, predators, human disturbance, oil spills, or other local events are substantially greater than if the population was more widely distributed at a number of smaller breeding colonies. Furthermore, intraspecific competition for food near seabird colonies may increase with increasing colony size, forcing birds to commute greater distances from the colony to forage and causing density-dependent declines in nesting success (Ashmole 1963, Furness and Birkhead 1984). Furthermore, if the availability of marine forage fish off the coast of the Pacific Northwest declined to levels observed during the early 1990s (Emmett and Brodeur 2000), terns nesting on East Sand Island may become more reliant on juvenile salmonids as a food source. Close monitoring is needed to assess the long-term effects of the relocation of the Caspian tern colony on survival of juvenile salmonids, as well as the productivity and demography of Caspian terns in the Columbia River estuary.

MANAGEMENT IMPLICATIONS

To minimize risks to Columbia Basin salmonids and Caspian terns, long-term management could

include attracting a portion of the Caspian tern colony on East Sand Island to nest at several new and/or restored colony sites outside the Columbia River estuary. Caspian terns formerly nested in large colonies (>1,000 pairs) on islands in Willapa Bay and Grays Harbor, estuaries that no longer support nesting Caspian terns. Caspian tern colonies also were located along the coast of Puget Sound near Everett and Tacoma, Washington, but these colonies have been intentionally destroyed (R. J. Beach, Washington Department of Fish and Wildlife, personal communication). The welfare of other listed or beleaguered salmonid stocks has been a primary concern in areas considered for restoration of Caspian tern colonies, yet for most former colony sites there is little or no evidence that juvenile salmonids were a significant component of tern diets. Restoration of permanent colony sites for Caspian terns along the coast of the Pacific Northwest appears unlikely without empirical evidence that local salmonid stocks will not be at risk. Toward that end, a study recently was conducted to test the feasibility of using small barges as temporary colony sites for Caspian terns as a means to assess diet composition of terns at potential colony restoration sites outside the Columbia River estuary (Collis et al. 2002*b*). The success of the pilot study suggests that this approach holds promise for providing resource managers with information on salmonid predation rates and tern nesting success needed to develop a science-based long-term management plan.

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