Barges as temporary breeding sites for Caspian terns: assessing potential sites for colony restoration

Ken Collis, Daniel D. Roby, Christopher W. Thompson, Donald E. Lyons, and Michelle Tirhi

Abstract Management proposals to reduce Caspian tern (*Sterna caspia*) predation on juvenile salmonids (*Oncorhynchus* spp.) in the Columbia River estuary include relocating some terns from the large colony in the estuary to several smaller colonies outside the Columbia River basin. The welfare of other listed or beleaguered salmonid stocks has been a primary concern in areas considered for restoration of Caspian tern colonies, demonstrating a need for empirical evidence on the effects of tern predation on fisheries prior to restoration of permanent colonies. The main objectives of this study were to determine 1) whether Caspian terns would readily use a barge as a temporary nesting site and 2) whether tern diet composition and productivity data could be collected at the barge. A small, sand-covered barge equipped with tern decoys and sound systems was anchored in Commencement Bay, Washington in 2001. Approximately 388 tern nests were initiated on the barge in a 17-day time period. We monitored diet composition at the barge site by direct observation of fish (n=1,097) in the bills of nesting adults. Tern diets during May were 65% juvenile salmonids; marine forage fishes comprised the remainder of the diet. Predation on tern eggs by glaucous-winged gulls (*Larus glaucescens*) was frequently observed during the first 10 days following the onset of egg laying; however, predation declined once incubating terns were densely packed on the barge. This study demonstrated that terns might rapidly colonize a barge and that diet composition and productivity data can be collected at the barge site. Barges may be used to assess prospective colony restoration sites; however, these efforts must be carefully conceived and coordinated with resource managers to avoid new resource management conflicts.

Key words Caspian tern, Commencement Bay, conservation, nesting barge, predation, salmonids, *Sterna caspia*

Caspian terns (*Sterna caspia*) nesting on dredged material disposal islands in the Columbia River estuary have utilized juvenile salmonids (*Oncorbynchus* spp.) as their primary food source (Collis et al. 2002, Roby et al. 2002). Tern predation might have had a significant impact on survival of some salmonid stocks in the Columbia River estuary (Collis et al. 2001), and most stocks in the Columbia River basin are listed as threatened or endangered under the United States Endangered Species Act (ESA; National Marine Fisheries Service [NMFS] 2002). Management actions to reduce the impact of Caspian terns on juvenile salmonid survival have included relocating terns nesting on an island in the upper Columbia

Address for Ken Collis: Real Time Research, 201 Yellowtail Hawk Avenue, Bend, OR 97701, USA; e-mail: kcollis@realtimeresearch.org. Address for Daniel D. Roby and Donald E. Lyons: United States Geological Survey-Oregon Cooperative Fish & Wildlife Research Unit, Department of Fisheries and Wildlife, 104 Nash Hall, Oregon State University, Corvallis, OR 97331-3803, USA. Address for Christopher W. Thompson: Washington Department of Fish and Wildlife, 16018 Mill Creek Boulevard, Mill Creek, WA 98012, USA. Address for Michelle Tirhi: Washington Department of Fish and Wildlife, 25644 44th Avenue S., Kent, WA 98032, USA.

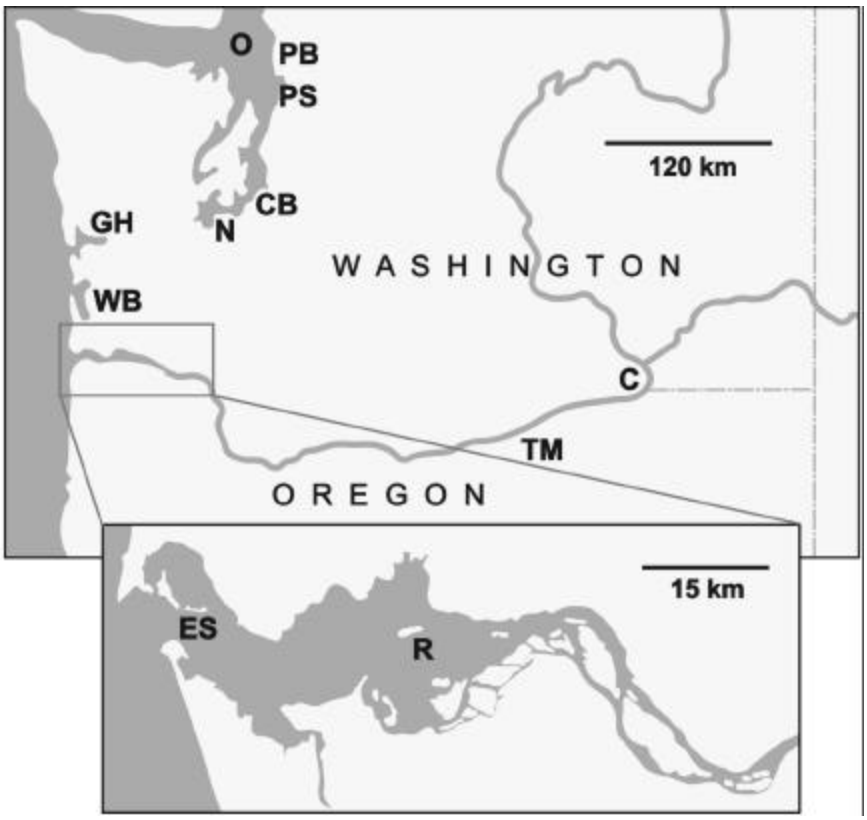

Figure 1. Map of the Columbia River, Columbia River estuary, and coastal Washington shows the locations of East Sand Island (ES), Rice Island (R), Three Mile Canyon Island (TM), Crescent Island (C), Willapa Bay (WB), Grays Harbor (GH), Nisqually National Wildlife Refuge (N), Commencement Bay (CB), Possession Sound (PS), Padilla Bay (PB), and Orcas Island (O). Base map courtesy of Thompson et al. (2002).

River estuary (Rice Island; Figure 1) to a restored colony site lower in the estuary (East Sand Island; Figure 1), where terns were expected to be less reliant on juvenile salmonids as a food source (United States Army Corps of Engineers [USACE] 2001). Efforts to relocate the colony were successful; terns nesting on East Sand Island experienced higher nesting success and consumed significantly fewer juvenile salmonids than their counterparts on Rice Island (Columbia Bird Research [CBR] 2002, Roby et al. 2002). Despite this reduction in predation associated with the relocation of nesting terns from Rice Island to East Sand Island, terns continue to consume millions of juvenile salmonids from the Columbia River basin annually (CBR 2002). Further reductions in tern consumption of ESA-listed juvenile salmonids from the Columbia River basin are unlikely without reductions in the size of the breeding colony on East Sand Island.

In 2001 the East Sand Island Caspian tern colony consisted of approximately 8,900 breeding pairs, the largest of its kind in North America (Cuthbert and Wires 1999, Wires and Cuthbert 2000) and perhaps the world. This was the sole Caspian tern colony on the Pacific Northwest coast in 2001 (CBR 2002). This one colony represents about 25% of Caspian terns nesting in North America and perhaps 10% of worldwide numbers of the species (Wires and Cuthbert 2000). Caspian terns are of conservation concern on a global scale because the total worldwide population probably does not exceed 100,000 pairs, colonies are small and scattered over large areas, and populations have declined in much of their former range in the Old World (Cramp 1985, Hagemeijer and Blair 1997, Cuthbert and Wires 1999). Eight former Caspian tern colony sites on the coast of the Pacific Northwest have been abandoned for a variety of reasons, mostly anthropogenic (Collis et al. 1999), and the displaced breeding pairs have coalesced in the Columbia River estuary (Roby et al. 1998). Caspian tern conservation in the Pacific Northwest likely would be enhanced by the restoration of former colonies or the creation of new colonies so that breeding is not concentrated at a single site, thereby reducing the risk from catastrophic local events (e.g., oil spills, storms, predators, disease outbreaks, human disturbances).

One approach toward further reducing losses of ESA-listed juvenile salmonids to Caspian terns is to relocate a portion of the terns currently nesting on East Sand Island to new and restored colony locations outside the Columbia River basin where alternative prey are available and impacts to ESA-listed stocks might be reduced (USACE 2001). This approach could also provide benefits to Caspian terns by redistributing nesting activities over a

broader geographic area and a larger number of sites, thereby decreasing the risks to this tern population from local catastrophes. Restoration of alternative colony sites along the coast of the Pacific Northwest has not been initiated, however, due in large part to concerns for 1) salmonid stocks near potential sites for restored or new tern colonies and 2) the welfare of the terns themselves. Many bays and estuaries along the coast of the Pacific Northwest are habitat for ESA-listed or declining runs of salmonids (NMFS 2002). Also, low food availability or locally abundant nest predators might render some former or prospective tern colony sites as population sinks (Penland 1982). Gaining information about potential impacts on both local fisheries and the Caspian tern population of establishing new tern colonies outside the Columbia River estuary is critical for deciding whether to restore colonies along the coast of the Pacific Northwest and, if so, where those colonies should be located.

A study has shown that the diet composition of Caspian terns is not a simple function of local availability of forage fishes (Collis et al. 2001). Caspian terns can travel considerable distances from their nesting colonies to foraging areas (e.g., 70 km, Soikkeli 1973; 50 km, K. Collis, unpublished data), suggesting that impacts of tern predation on local fish stocks of special concern can not be predicted *a priori* by sampling fish in the vicinity of a proposed colony restoration site. As a method to assess diet composition and productivity of terns at a potential colony restoration site, we tested the feasibility of attracting Caspian terns to nest on a barge that served as a temporary colony site. The main objectives of this study were to determine 1) whether terns would readily use a barge as a nesting site and 2) whether tern diet composition and productivity data could be collected at the barge.

Methods

We selected Commencement Bay, Washington as the site to test the feasibility of using barges as temporary colony sites for Caspian terns. We chose this site because terns that had formerly nested on the shores of Commencement Bay at the American Smelting and Refining Company (ASARCO) Industrial Site (Shugart and Tirhi 2001, Thompson et al. 2002) were prevented from nesting there in 2001 due to scheduled cleanup of contaminated soil at the site. We were particularly interested in this colony as a conservation site because it was the only Caspian tern colony on the coast of Washington and apparently no alternative nesting habitat was available. Furthermore, without an alternative nest site for terns in Commencement Bay, regional resource managers were concerned that the terns displaced from the ASARCO site might attempt to nest in the Columbia River estuary, further contributing to tern predation on juvenile salmonids from the Columbia River basin (B. Meyer, NMFS, personal communication).

We anchored a barge in Commencement Bay near Browns Point on 13 April 2001 (Figure 2), and monitored it on a daily basis until 31 May 2001 (see below). We anchored the barge about 100 m offshore, approximately 7 km east of the former Caspian tern colony at the ASARCO Industrial Site (Figure 2). The shoreline of Commencement Bay was entirely within the city limits of Tacoma, Washington. We chose the barge anchorage site to minimize navigational hazards and disturbance from commercial and recreational watercraft. We deployed the tern nesting barge to coincide with the arrival of most Caspian terns from the wintering grounds

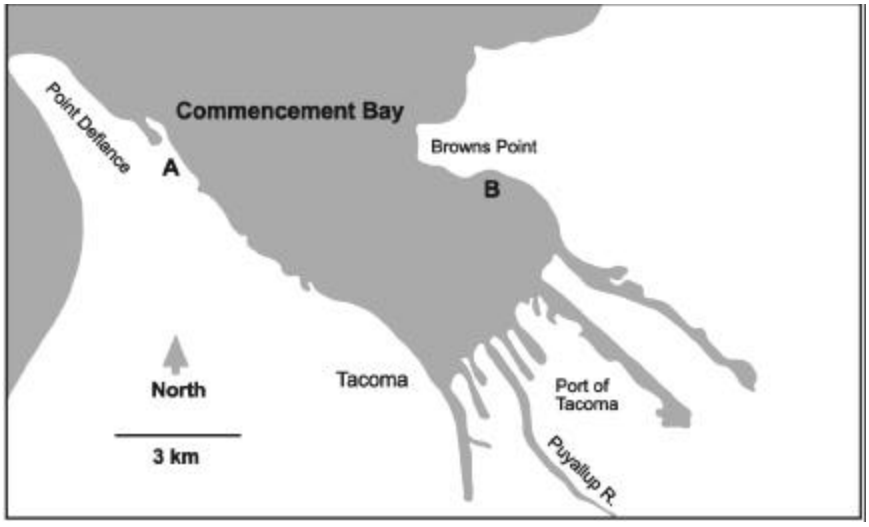

Figure 2. Map of Commencement Bay, Washington shows the location of the nesting colony at the ASARCO Industrial Site used in 1999 and 2000 (A) and the location of the tern nesting barge deployed near Browns Point in 2001 (B).

(i.e., late April and early May; Shugart and Tirhi 2001).

The deck of the barge measured 27.4 × 12.2 m and was roughly 2 m above the water surface. We secured logs (approx. 0.5 m in diameter) to the perimeter of the barge deck and spread sand, the preferred nesting substrate of Caspian terns (Quinn and Sirdevan 1998), over the deck within the retainer logs to a depth of 20–30 cm. The total area of sand-covered deck was 259.4 m^2. We evenly spaced 99 Caspian tern decoys (Mad River Decoys, Waitsfield, Vt.) and 4 solar-powered audio playback speakers (Murre Maid Music Boxes, South Bristol, Me.) that broadcast digital recordings of Caspian tern calls (Alaska's Spirit Speaks, Fairbanks, Alas.) across the deck of the barge to provide social attraction and encourage prospecting terns to settle and nest on the barge (see Kress 1983). We placed 2 solar panels and 2 compact disk players on the bow of the barge, outside the log retainers.

Initially, we set up an elevated observation blind onshore above the high-tide line so that we could monitor tern activity on the barge. Later, once terns had begun nesting on the barge, we moved the blind to a floating platform anchored about 25 m from the barge. Because terns transport whole fish in their bills to their mates and young at the colony, we could determine diet composition of terns nesting on the barge with the aid of binoculars by direct observation of adults as they returned to the colony with fish ("bill loads"). Two trained observers identified prey items at the barge each day from 14–31 May, corresponding to the period when terns first settled on the barge (pre-egg laying) through egg laying. We conducted observations primarily in the early morning and late afternoon, and so they were considered random with respect to tide stage. We identified prey to the lowest discernible taxa; we were confident we could distinguish between salmonids and nonsalmonids, and among most nonsalmonid taxa based on direct observations from the blind (see Roby et al. 2002). Comparisons between observers in the percent of the diet that were salmonids versus nonsalmonids were not significantly different during a 3-day period (17–19 May) when both observers were conducting observations (χ^2=0.07, P=0.78).

Additionally, we monitored bird activity on or near the barge each day (i.e., primarily in the early morning and late afternoon) throughout the duration of the project (13 April–31 May, 2001). During each observation period, we counted the number of terns on the barge (both nesting and roosting) at 5- to 30-min intervals, depending on the number of terns on the barge. Also, we continuously monitored the activity of predators (glaucous-winged gulls [*Larus glaucescens*], bald eagles [*Haliaeetus leucocephalus*], and American crows [*Corvus brachyrhynchos*]) and all other disturbances at the barge colony (e.g., pedestrians on the beach, boat traffic).

Because of a breakdown in interagency coordination, not all necessary permits were obtained by the Washington Department of Fish and Wildlife prior to placement of the barge in Commencement Bay. We discovered this problem soon after terns began nesting on the barge, and on 25 May 2001 federal, state, tribal, and local resource managers decided to collect all eggs on the barge and remove the barge from Commencement Bay prior to any tern eggs hatching (J. B. Bortner, United States Fish and Wildlife Service, personal communication). We determined the density of initiated nests and number of eggs laid on the barge immediately prior to the barge's removal from Commencement Bay on 31 May. Following removal of the barge (1–21 June), we conducted weekly surveys by road, boat, or fixed-winged aircraft in Commencement Bay, south Puget Sound, the southwest coast of Washington, and the Columbia River estuary for Caspian terns (Figure 1) displaced from the barge colony in Commencement Bay (CBR 2002).

Results

The first Caspian terns sighted were along the shores of Commencement Bay on 23 March, 3 weeks prior to anchoring the barge near Browns Point. Although we observed Caspian terns circling the barge soon after it was deployed, terns did not utilize the barge for roosting until 14 days after the barge was anchored in Commencement Bay. On 27 April, 2 terns landed briefly on the barge. For the next 2 weeks, small numbers of Caspian terns (<10 individuals) occasionally landed on the tern barge (near the center) but did not remain for extended periods (i.e., less than one hour).

Meanwhile, adult terns were periodically disturbed and flushed by workers and equipment at ASARCO (7 km west of the barge) with the objective of discouraging Caspian terns from nesting at any of several roost sites there. Also, ASARCO personnel covered the mounds where Caspian terns had nested in 1999 and 2000 with new plastic tarps

so that terns no longer had access to nesting substrate. In addition, personnel from the University of Puget Sound and the Washington Department of Fish and Wildlife initiated cannon-netting for the purpose of banding adults with unique color combinations of plastic leg bands at the ASARCO site soon after the barge was deployed in Commencement Bay. A total of 54 adult terns were cannon-netted and banded at the ASARCO site in late April and early May 2001 (G. W. Shugart, University of Puget Sound, unpublished data). Nevertheless, terns showed strong fidelity to the ASARCO Industrial Site through mid-May, with up to 400 terns roosting on any of several mounds at the site, despite periodic disturbance and lack of suitable nesting substrate (i.e., sandy material in which to dig nest scrapes). During late April and early May, Caspian terns displayed little interest in nesting at other locations in Commencement Bay, including the tern barge at Browns Point.

Figure 3. View of the tern barge anchored in Commencement Bay, Washington shows tern decoys, audio playback system, solar panel, and nesting Caspian terns. Photo was taken on 26 May 2001 from the observation blind located on a separate floating platform about 25 m from the tern barge. Photo courtesy of Michael Wilhelm.

On 14 May, 2 terns settled near the center of the barge and dug a nest scrape. Early the next day, the female tern laid an egg in the scrape, and the pair began incubating. On 17 May that nesting pair was joined by 15 more terns prospecting for nest sites, after which terns rapidly initiated nests on the barge until it was removed on 31 May. During this period we re-sighted on the tern barge 13 color-banded Caspian terns (24%) that had been captured and banded at the ASARCO site earlier that season. The maximum count of adult Caspian terns on the barge was 389 on 27 May.

During the first week after nesting was initiated, egg predation and kleptoparasitism rates by glaucous-winged gulls at the barge were intense (e.g., gulls preyed on eggs from 12 different nests during observations on 19–20 May), and we were unsure whether the colony would persist. Gull predation on tern eggs was often associated with disturbances to the colony by nearby boaters or overflights by bald eagles, a known predator of adult terns (Cuthbert and Wires 1999). By 24 May, however, nesting and roosting terns were densely packed on the barge (Figure 3) and gull predation on tern eggs declined dramatically. Thereafter, we observed few gulls on the tern barge.

Between 14 and 31 May, we identified 1,097 bill-load fish at the tern barge (Table 1). Overall, juvenile salmonids were the most prevalent prey type for terns nesting on the barge (64.7% of prey items), followed by unidentified nonsalmonids

Table 1. Diet composition (% identifiable prey items) of Caspian terns nesting on a barge anchored near Browns Point in Commencement Bay, Washington in 2001 as indicated by courtship bill-load fish delivered to the tern colony.

Prey type	May 14–19	May 20–25	May 26–31	Overall
Salmonid[a]	64.4	64.1	65.7	64.7
Herring, sardine[b]	8.9	15.4	6.1	10.1
Surfperch[c]	8.9	4.9	8.8	7.5
Sand lance[d]	4.4	0.4	0.4	1.7
Smelt[e]	3.3	0.4	0.7	1.5
Lamprey[f]	1.1	0.4	2.1	1.2
Anchovy[g]	1.1	0.2	0.2	0.5
Unidentified nonsalmonid	7.8	14.1	16.1	12.7
Sample size	90	448	559	1,097

[a] *Oncorhynchus* spp.; [b] Clupeidae; [c] Embiotocidae; [d] Ammodytidae; [e] Osmeridae; [f] *Lampetra* spp.; [g] Engraulidae.

(12.7%), clupeids (herring and sardines, 10.1%), and embiotocids (surfperch, 7.5%). The percentage of salmonids in tern diets was consistent during the 18-day observation period, ranging from 64.4% to 65.7% for the 3 consecutive 6-day periods when we collected diet data (Table 1).

During the week prior to removal of the tern barge (25–31 May), large numbers of Caspian terns were attracted to its vicinity by the nesting activity. On 25 May we observed 400–500 adult terns roosting on a large barge moored about 500 m from, and in view of, the tern barge. By the end of the day, the terns had left the large barge, abandoning at least 14 eggs laid on its metal deck; gulls soon removed all tern eggs. Two days later (27 May), we counted about 690 terns on an adjacent large barge; as many as 50 appeared to be incubating eggs on the barge deck. Two days after the second large barge was colonized (29 May), we counted 614 terns on the barge; a disturbance that flushed all the terns revealed that 22 eggs had been laid there. A few days later and about the same time the tern barge was removed (see below), the terns disappeared from the second large barge, abandoning the eggs laid there.

Just prior to removal of the tern barge from Commencement Bay on 31 May, personnel from the Washington Department of Fish and Wildlife collected all tern eggs laid on it. They collected 980 tern eggs, at least 235 of which had apparently been abandoned because they were found outside of nest scrapes. We counted 388 nest scrapes that contained eggs (1–4 eggs/nest); these nest scrapes contained an average of 1.9 eggs. Although some of these nests might have been abandoned at the time eggs were collected from the barge, average clutch size of nests at 2 Caspian tern colonies in the lower Columbia River were 2.0 and 2.1 eggs/nest (D. D. Roby, unpublished data). This suggested that most clutches in nest scrapes were complete and being incubated at the time they removed the eggs. Consequently, the best estimate of number of tern nests initiated on the barge was 388, corresponding to an average nesting density on the barge of 1.5 nests/m^2.

Tug moves the tern barge to the anchorage site in Commencement Bay, Washington. Photo courtesy of Don Lyons.

The day after the barge was removed from Commencement Bay (1 June), the large numbers of terns that had been roosting and dumping eggs on the decks of the nearby large barges disappeared. We counted only 175 adult Caspian terns in the Commencement Bay area, compared to bay-wide counts ranging from 675 to 900 adult terns prior to barge removal. Counts of terns in the Commencement Bay area in June and early July never exceeded 200 adults. In late July we observed up to 700 post-breeding terns, presumably from the Columbia River estuary, at various locations in Commencement Bay. Subsequent to barge removal, we did not find any new nesting aggregations during surveys conducted in south Puget Sound from Orcas Island in the north to Nisqually National Wildlife Refuge in the south and along the southwest Washington Coast from Grays Harbor in the north to the Columbia River estuary in the south (Figure 1).

After the barge was removed, we resighted 2 of 13 color-banded terns (15%) originally sighted at the tern barge in Commencement Bay at the large Caspian tern colony on East Sand Island in the Columbia River estuary (Figure 1). This suggested that at least some of the terns that had left Commencement Bay following barge removal joined the breeding population of Caspian terns in the Columbia River estuary. We saw 1 of the 2 color-banded terns re-sighted on East Sand Island among a group of late-nesting terns still incubating eggs.

Discussion

Our results demonstrated that Caspian terns lacking alternative nesting sites could be attracted to nest on a sand-covered barge using social attractants in the first season of deployment. Floating nest platforms ("rafts") have been used previously by breeding terns; however, in each case the raft was situated <1 km from a former tern colony (Lampman et al. 1996) or commonly used loafing area (Dunlop et al. 1991). In this study we showed

that terns will colonize a barge 7 km from a former colony site and 4 km from the nearest loafing area (i.e., mouth of the Puyallup River; Figure 2). These findings are significant if barges are used to assess the suitability of sites for restoration of tern colonies (i.e., potential colony sites might be located considerable distances from tern nesting or loafing sites).

Nevertheless, this study to attract terns to nest on a barge in Commencement Bay in 2001 benefited from the proximity of a displaced breeding population (i.e., ASARCO), and the apparent absence of other available nesting habitat in the area. The nearest known Caspian tern colony site in 2001 was approximately 170 km away in the Columbia River estuary (Figure 1). Efforts to attract terns to barges or other colony sites from a source population farther than this or in an area with alternative suitable nesting habitat might proceed at a slower pace.

Other factors that likely would affect successful colonization of nesting barges by Caspian terns include 1) inter-specific competition for nest sites, 2) rates of kleptoparasitism and predation, and 3) human disturbance (see Quinn et al. 1996). Previous attempts to attract terns to breed on nesting rafts have demonstrated that gulls, which sometimes initiate nesting earlier than terns, might need to be controlled or precluded from nesting on the raft in order for nesting terns to become established (Morris et al. 1992, Lampman et al. 1996). Furthermore, intense gull predation on Caspian tern eggs and chicks, often associated with disturbance by humans and other predators that cause terns to leave their nests unattended, is believed to be a major factor limiting tern nesting success and causing colony abandonment (Penland 1982, Quinn 1984, Cuthbert and Wires 1999). Efforts to restore tern breeding colonies often require selective removal of predatory gulls (Kress 1983, Quinn et al. 1996) while concurrently minimizing human disturbance of the colony (see Cuthbert and Wires 1999).

View of the observation blind on a floating platform adjacent to the tern barge. Photo courtesy of Michael Wilhelm.

Caspian tern flies over the tern barge with a juvenile salmonid in its bill. Photo courtesy of Michael Wilhelm.

Glaucous-winged gulls did not use the tern barge in Commencement Bay as a nest site or regular roosting site prior to arrival of Caspian terns, eliminating the need to cover the colony area with a tarpaulin to prevent gulls from colonizing the barge (see Lampman et al. 1996). Once terns began laying eggs on the barge, several gulls visited the site regularly to prey on tern eggs and kleptoparasitize fish bill loads from adult terns. Initially, gulls were successful in removing several dozen tern eggs from the barge, but once the barge was fully occupied by nesting terns (ca. 24 May), gull use of the barge for foraging declined dramatically, eliminating any possible need for selective gull control. Despite the location of the barge near a major urban area with high boat traffic, terns were infrequently flushed from their nests, perhaps because they had become habituated to human disturbance at the ASARCO site and elsewhere.

We were successful in collecting data to assess diet composition at the barge from 14 May, when terns initially colonized the barge, until the barge was removed on 31 May. Although the diet data indicated that terns nesting on the barge relied primarily on juvenile salmonids as a food source (65% of identified bill-load fish), these data were not likely representative of the diet composition of Caspian terns nesting at the barge throughout the entire breeding season (mid-April through August). Diet composition data collected in Commencement Bay

at the ASARCO Industrial Site in 2000 ($n = 1,540$ bill-load fish) indicated that juvenile salmonids comprised 55%, 64%, and 36% of the tern diet in May, June, and July, respectively (Thompson et al. 2002).

Large numbers of adult Caspian terns (400–700 individuals) began roosting and dumping eggs on the bare metal decks of large barges moored about 500 m from the tern barge just prior to its removal. This suggested that the breeding activity of terns nesting on the tern barge attracted additional terns, which were unable to find space to nest on the tern barge or suitable alternative nesting sites elsewhere in Commencement Bay. This interpretation is supported by the high density of tern nests recorded on the tern barge just prior to its removal. The highest nesting densities previously recorded at Caspian tern colonies in the Pacific Northwest were 0.9 nests/m^2 at both Three Mile Canyon and Crescent islands, in the lower Columbia River (M. Antolos, Oregon State University, unpublished data; Figure 1). The nesting density on the Commencement Bay tern barge (1.5 nests/m^2) was about 70% greater than at these 2 high-density colonies. Nesting densities of Caspian terns at colonies in the Columbia River estuary, the closest active colonies to Commencement Bay, are in the range of 0.3 to 0.8 nests/m^2 (Roby et al. 2002). These observations support the conclusion that nesting habitat for Caspian terns is extremely limited in the south Puget Sound area.

Establishment of temporary tern colonies on barges had advantages over attracting terns to nest on islands or mainland sites. First, suitable tern nesting habitat could be prepared quickly and often less expensively. Second, barges could be situated and relocated to suit the needs of resource managers. Third, tern colony size could be controlled to some extent by the size of the barge used. Finally, if after the establishment of a barge colony it was determined that the site was unsuitable for tern nesting (i.e., terns had a significant impact on local fisheries of concern or nesting success of terns at the site was inadequate to balance mortality), terns could be precluded from attempting to nest at that site in the future by simply removing the barge. Alternatively, if it was determined that the locale was appropriate for tern nesting in the long term, resource managers could create suitable nesting habitat for Caspian terns and likely attract terns to return and breed in future years.

Management implications

Caspian terns continue to consume about 6 million juvenile salmonids in the Columbia River estuary annually, despite the reduction in smolt consumption associated with relocation of the tern colony from Rice Island to East Sand Island (CBR 2002). Based on smolt passive integrated transponder tags recovered from the East Sand Island tern colony in 2000 and 2001 (Ryan et al. 2001*a*,*b*), some ESA-listed salmonid stocks from the Columbia River basin continue to suffer significant losses to tern predation. In 2001, approximately two-thirds of Caspian terns in the Pacific coast population of North America were nesting at East Sand Island, the sole Caspian tern colony site on the coast of the Pacific Northwest (Cuthbert and Wires 1999, Wires and Cuthbert 2000). Risks to both the tern population and Columbia Basin salmonids might be reduced if a portion of the Caspian tern colony in the Columbia River estuary was relocated to a number of smaller tern colonies outside the Columbia River. The use of barges as temporary colony sites for Caspian terns could help assess the diet and productivity of terns at prospective colony restoration sites. Food-habits studies of terns using barges are especially crucial because these data could be used in models to estimate consumption, information needed to assess the potential impacts of a larger, permanent tern colony on the survival of local forage fish species of special concern, especially juvenile salmonids. The use of barges as temporary colony sites could be part of a comprehensive effort to evaluate the suitability of alternative sites for restoration of tern colonies along the coast of the Pacific Northwest and elsewhere.

Grays Harbor, Willapa Bay, Possession Sound, and Padilla Bay (Figure 1) are all former Caspian tern colony sites along the coast of Washington (Collis et al. 1999) and are potential sites for deployment of barges. Little or no data are available on diet composition and factors limiting nesting success of Caspian terns at these former colonies, so temporary colonies on barges would help fill in these information gaps. Efforts to deploy tern barges must, however, be carefully conceived and coordinated with resource managers in agencies representing federal, state, tribal, and local stakeholder interests if new resource management conflicts are to be avoided. Identifying and implementing Caspian tern management options to benefit salmonids and terns in the Pacific Northwest will

require both interagency cooperation and innovative approaches.

Acknowledgments. This project was funded by the United States Geological Survey (using funds designated by the United States Fish and Wildlife Service), the United States Army Corps of Engineers (USACE), and the National Marine Fisheries Service (NMFS). We thank B. Bortner (USFWS), T. Zimmerman (USFWS), R. Willis (USACE), G. Dorsey (USACE), and B. Meyer (NMFS) for help in securing project funding. S. K. Anderson, C. Cardoni, L. Leonard, S. McDougal, D. Moskowitz, A. M. Myers, J. Rozier, N. Spang, R. Suryan, S. Wright, and numerous volunteers provided invaluable assistance in the field. R. Beach, G. Dorsey, M. Hawbecker, J. Henry, K. Larson, R. Larson, M. Nichols, S. Schubel, G. Shugart, R. Suryan, K. Turco, and J. Whitney provided equipment, services, or logistical support for which we are very grateful. B. Bortner, T. Zimmerman, D. Craig, R. Morris, and two anonymous reviewers provided helpful comments that improved earlier drafts of this paper.

Literature cited

Collis, K., S. L. Adamany, D. D. Roby, D. P. Craig, and D. E. Lyons. 1999. Avian predation on juvenile salmonids in the lower Columbia River. 1998 Annual Report of the Oregon Cooperative Fish and Wildlife Unit at Oregon State University to Bonneville Power Administration and United States Army Corps of Engineers, Portland, USA.

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

Collis, K., D. D. Roby, D. P. Craig, B. A. Ryan, and R. D. Ledgerwood. 2001. Colonial waterbird predation on juvenile salmonids tagged with passive integrated transponders in the Columbia River Estuary: vulnerability of different salmonid species, stocks, and rearing types. Transactions of the American Fisheries Society 130: 385–396.

Columbia Bird Research. 2002. Caspian tern research on the lower Columbia River: 2001 draft season summary. Real Time Research, Bend, Oregon, USA. Available online at http://www.columbiabirdresearch.org (Accessed 17 January 2002).

Cramp, S., editor. 1985. Handbook of the birds of Europe, the Middle East and North Africa: the birds of the Western Palearctic. Volume 4. Oxford University Press, New York, New York, USA.

Cuthbert, F. J., and L. R. Wires. 1999. Caspian tern (*Sterna caspia*). Account No. 403 *in* A. Poole and F. Gill, editors. The Birds of North America. Academy of Natural Sciences, Philadelphia, Pennsylvania, and American Ornithologists' Union, Washington D.C., USA.

Dunlop, C. L., H. Blokpoel, and S. Jarvie. 1991. Nesting rafts as a management tool for a declining common tern (*Sterna hirundo*) colony. Colonial Waterbirds 14: 116–120.

Hagemeijer, E. J., and M. J. Blair. 1997. The EBCC Atlas of European Breeding Birds: their distribution and abundance. Poyser, London, United Kingdom.

Kress, S. W. 1983. The use of decoys, sound recordings, and gull control for re-establishing a tern colony in Maine. Colonial Waterbirds 6: 185–196.

Lampman, K. P., M. E. Taylor, and H. Blokpoel. 1996. Caspian terns (*Sterna caspia*) breed successfully on a nesting raft. Colonial Waterbirds 19: 135–138.

Morris, R. D., H. Blokpoel, and G. D. Tessier. 1992. Management efforts for the conservation of common tern *Sterna hirundo* colonies in the Great Lakes: two case histories. Biological Conservation 60: 7–14.

National Marine Fisheries Service. 2002. Endangered Species Act status of west coast salmonids, December 26, 2001. National Marine Fisheries Service, Northwest Region, Portland, Oregon, USA. Available online at http://www.nwr.noaa.gov (Accessed 17 January 2002).

Penland, S. 1982. Distribution and status of the Caspian tern in Washington State. Murrelet 63: 73–79.

Quinn, J. S. 1984. Egg predation reduced by nest covers during research activities in a Caspian tern colony. Colonial Waterbirds 7: 149–151.

Quinn, J. S., R. D. Morris, H. Blokpoel, D. V. Weseloh, and P. J. Ewins. 1996. Design and management of bird nesting habitat: tactics for conserving colonial waterbird biodiversity on artificial islands in Hamilton Harbour, Ontario. Canadian Journal of Fisheries and Aquatic Sciences 53: 45–57.

Quinn, J. S., and J. Sirdevan. 1998. Experimental measurement of nesting substrate preference in Caspian terns, *Sterna caspia*, and the successful colonization of human constructed islands. Biological Conservation 85: 63–68.

Roby, D. D., D. P. Craig, K. Collis, and S. L. Adamany. 1998. Avian predation on juvenile salmonids in the lower Columbia River. 1997 Annual Report of the Oregon Cooperative Fish and Wildlife Research Unit at Oregon State University to Bonneville Power Administration and United States Army Corps of Engineers, Portland, USA.

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

Ryan, B. A., J. H. Glabek, J. W. Ferguson, E. P. Nunnallee, and R. D. Ledgerwood. 2001*a*. Detection of passive integrated transponder (PIT) tags on piscivorous bird colonies in the Columbia River basin, 2000. Report of Research, Northwest Fisheries Science Center, National Marine Fisheries Service/National Oceanic Atmospheric Administration, Seattle, Washington, USA.

Ryan, B. A., E. P. Nunnallee, J. H. Glabek, and J. W. Ferguson. 2001*b*. Recovery of passive integrated transponder tag codes from piscivorous bird colonies in the Columbia River basin. 2001 Annual Research Review, Anadromous Fish Evaluation Program, United States Army Corps of Engineers, Portland, Oregon, USA. (Abstract only).

Shugart, G. W., and M. Tirhi. 2001. Nesting by Caspian terns in lower Puget Sound, Washington during 1999. Northwestern Naturalist 82: 32–35.

Soikkeli, M. 1973. Long-distance fishing flights of the breeding Caspian tern *Hydroprogne caspia*. Ornis Fennica 50: 47–48.

Thompson, C. W., E. R. Donelan, M. M. Lance, and A. E. Edwards. 2002. Diet of Caspian terns in Commencement Bay, Washington. Waterbirds 25: 78–85.

UNITED STATES ARMY CORPS OF ENGINEERS. 2001. Caspian tern relocation FY 2001–2002 management plan and pile dike modification to discourage cormorant use, lower Columbia River, Oregon and Washington. Environmental Assessment and Finding of No Significant Impact, United States Army Corps of Engineers, Portland, Oregon, USA.

WIRES, L. R., AND F. J. CUTHBERT. 2000. Trends in Caspian tern numbers and distribution in North America: a review. Waterbirds 23:388–404.

Ken Collis (photo) is the founder of Real Time Research, a private environmental and data consulting firm. For more than 10 years, Ken has been leading studies on predator–prey interactions on the lower Columbia River and has assisted resource managers in implementing management initiatives to reduce predation-related mortality on juvenile salmonids from the Columbia River basin. Currently, Ken is the co-principal investigator on a study of avian predation on juvenile salmonids in the lower Columbia River. Ken received a B.S. degree in biology from Lewis and Clark College (1983) and an M.S. in zoology from the University of Maryland (1990). ***Daniel D. Roby*** is the assistant unit leader at the United States Geological Survey–Oregon Cooperative Fish and Wildlife Research Unit and an associate professor (courtesy) in the Department of Fisheries and Wildlife, Oregon State University. Dan has been conducting research on the breeding biology and nesting ecology of colonial waterbirds for more than 20 years. His research has focused on the diet composition and reproductive energetics of seabirds, and how these factors influence nesting success. Currently, Dan is the principal investigator on a study of avian predation on juvenile salmonids in the lower Columbia River. He received a B.S. in biology at Antioch College (1974), an M.S. in wildlife management from the University of Alaska (1978), and a Ph.D. in biology from the University of Pennsylvania (1986). ***Christopher W. Thompson*** is a research scientist with the Washington Department of Fish and Wildlife. Chris has been an active participant in the Caspian Tern Working Group for several years and is currently the principal investigator on a study of the impacts of piscivorous waterbirds at selected dams on the mid-Columbia River. Chris received a B.S. degree in biology from Princeton (1980), an M.S. in zoology from the University of Texas at Austin (1988), and a Ph.D. in zoology from Arizona State University at Tempe (1991). ***Donald E. Lyons*** is a graduate student with the United States Geological Survey–Oregon Cooperative Fish and Wildlife Research Unit, Department of Fisheries and Wildlife, Oregon State University. Don's graduate work has focused on the foraging ecology and smolt consumption rates of piscivorous waterbirds in the lower Columbia River. He received a B.S. from Iowa State University (1987) and an M.S. from University of California, Berkeley (1989), both in electrical engineering. ***Michelle Tirhi*** is an urban wildlife biologist with the Washington Department of Fish and Wildlife. Michelle has actively managed a colony of Caspian terns in Commencement Bay, Tacoma, Washington since 1997. Caspian tern management consists of interacting with private and commercial property owners in the Bay, assisting with ongoing research including locating permanent nesting sites, and monitoring colony status. Michelle received a B.S. degree in wildlife management from Washington State University (1989).

Associate editor: *Kilgo*