

AN ABSTRACT OF THE THESIS OF

Michelle Antolos for the degree of Master of Science in Wildlife Science presented on October 16, 2002.

Title: Breeding and Foraging Ecology of Caspian Terns (*Sterna caspia*) in the Mid-Columbia River: Predation on Juvenile Salmonids and Management Implications

Abstract approved: _____
Daniel D. Roby

I investigated Caspian terns (*Sterna caspia*) breeding at colonies on the Columbia Plateau (southeastern Washington and northeastern Oregon), with emphasis on the breeding and foraging ecology of Caspian terns nesting at colonies in the mid-Columbia River. I focused research at colonies where Caspian terns foraged on juvenile salmonids (*Oncorhynchus* spp.) because of potential impacts to stocks listed under the U.S. Endangered Species Act. Caspian tern colony size on the Columbia Plateau ranged from tens of breeding pairs to nearly 700 pairs at Crescent Island in the mid-Columbia River; total population size in the study area was about 1,000 pairs and appeared to be stable. The size and number of Caspian tern colonies in the Columbia Plateau region are likely constrained by the availability of suitable nesting habitat near abundant prey, a resource that appears limited within the study area. Productivity of Caspian terns was not affected by nest density at Crescent Island, information that may be helpful for resource managers deciding minimum area requirements for breeding Caspian terns at managed colony sites. At colonies on the mid-Columbia River, the majority of Caspian tern prey items consisted of juvenile salmonids. I estimated that Caspian terns nesting at Crescent Island in the mid-Columbia River consumed 382,000-547,000 and 533,000-825,000 juvenile

salmonids during the breeding season in 2000 and 2001, respectively. Total salmonid predation by Crescent Island Caspian terns was less than that reported for some other predators in the Columbia River that have been managed to reduce predation rates on juvenile salmonids. The results of this research will be used by state, federal, and tribal resource managers to decide whether Caspian tern management is warranted at Crescent Island.

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Breeding and Foraging Ecology of Caspian Terns (*Sterna caspia*) in the Mid-Columbia River: Predation on Juvenile Salmonids and Management Implications

by
Michelle Antolos

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APPROVED:

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Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Michelle Antolos, Author

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BREEDING AND FORAGING ECOLOGY OF CASPIAN TERNS (*Sterna caspia*) IN THE MID-COLUMBIA RIVER: PREDATION ON JUVENILE SALMONIDS AND MANAGEMENT IMPLICATIONS

Chapter 1

GENERAL INTRODUCTION

Michelle Antolos

The decline of anadromous salmonids (*Oncorhynchus* spp.) in the Columbia River basin over the last century and a half has prompted state, federal, and tribal resource managers to investigate a multitude of strategies for promoting salmon recovery (Lichatowich 1999). More than half of the evolutionarily significant units (ESUs) of salmonids in the basin are currently listed under the U.S. Endangered Species Act (NMFS 2002), and all others have experienced major declines. While much of the focus of salmon restoration has been on the “four H’s” (improvement of freshwater and estuarine Habitat, increasing survival through the Hydrosystem, regulating human Harvest, and modifying Hatcheries [NRC 1996]), reducing the impacts of predation by marine mammals, fish, and birds on salmon survival has also been considered an important restoration strategy. In the Columbia River, predation on juvenile salmonids by piscivorous fish has been investigated in detail (Rieman et al. 1991), and has resulted in an extensive management program to control losses of smolts to predation by northern pikeminnow (*Ptychocheilus oregonensis*; Beamesderfer et al. 1996, Friesen and Ward 1999).

Avian predation has also been investigated as a potentially important source of mortality to juvenile salmonids in the Columbia River basin (Ruggerone 1986, York et al. 2000); studies of piscivorous birds in other river systems have demonstrated that avian predators can have major impacts on survival of juvenile salmonids (e.g., Wood 1987, Kennedy and Greer 1988, Feltham 1995). In the lower Columbia River, evidence of predation on threatened and endangered salmon ESUs by piscivorous birds prompted federal agencies to investigate the effects of avian predation on out-migrating juvenile salmonids (NMFS 1995). Caspian terns (*Sterna caspia*) breeding in the Columbia River estuary were of particular concern because of growing numbers and the large proportion of juvenile salmonids in their diet (Roby et al. 1998, Collis et al. 2002a). Researchers reported that Caspian terns nesting in the estuary consumed an

estimated 9.1-15.7 million juvenile salmonids during the 1998 out-migration (approximately 13% of the number of juvenile salmonids to reach the estuary; Roby et al. 2003), and the decision was made to manage this tern population in order to reduce its impact on survival of juvenile salmonids (USACE 1999).

While detailed studies of Caspian tern predation on juvenile salmonids have been conducted in the Columbia River estuary since 1997 (Roby et al. 1998, Collis et al. 1999, Collis et al. 2001, Collis et al. 2002a, Roby et al. 2002, Roby et al. 2003), the status, size, and predation impacts of smaller up-river tern colonies have not been examined in detail. Some data were, however, collected on Caspian tern colony size and diet in the mid-Columbia River in 1997 and 1998, and these data suggested that terns nesting on islands in the mid-Columbia River foraged primarily on juvenile salmonids (Collis et al. 2002a).

I investigated Caspian terns breeding at colonies on the Columbia Plateau (southeastern Washington and northeastern Oregon), with emphasis on the breeding and foraging ecology of Caspian terns nesting at colonies in the mid-Columbia River. Focused research was conducted in 2000 and 2001, and population trends between 1996 and 2001 were analyzed, in part to address concerns about changes to the number and size of up-river tern colonies following tern management in the estuary. I made detailed observations of Caspian tern diet at these colonies, data used to calculate estimates of salmonid consumption by terns at a single colony, and to gauge the magnitude of tern predation on juvenile salmonids within the study area. State, federal, and tribal fisheries managers will use these results to inform decisions regarding management of Caspian terns at these colonies.

In order to analyze the status of Caspian terns in the region, I investigated all known Caspian tern colonies on the Columbia Plateau, and addressed potential factors controlling the number and size of tern colonies within the study area. This information may assist in long-term management of this sub-population, as

well as contribute to demographic analyses of the Pacific Coast population of Caspian terns (e.g., Wires and Cuthbert 2000, Shuford and Craig 2002).

I also conducted a study at a Caspian tern colony on Crescent Island, in the mid-Columbia River, investigating the effects of nest density, location, and timing on tern breeding success. Assessing the effects of nest density on productivity can provide useful guidelines for management of Caspian tern nesting habitat. Because resource managers must make decisions regarding minimum area requirements for breeding Caspian terns at managed colony sites (e.g., at East Sand Island; Roby et al. 2002), it is important to understand the relationship between nest density and reproductive success.

In addition, I investigated predation on juvenile salmonids by Caspian terns breeding at Crescent Island in 2000 and 2001. I used a bioenergetics modeling approach to quantify the numbers of out-migrating juvenile salmonids consumed by Caspian terns at Crescent Island in 2000 and 2001, and investigated the foraging distribution and habitat use of terns near Crescent Island. I examined the relationship between densities of foraging terns and habitat type, as well as several environmental factors, in order to determine how tern predation is directed at out-migrating juvenile salmonids in the mid-Columbia River. The results of this study will provide state, federal, and tribal resource managers with information necessary to assess management strategies for Caspian terns at this site.

This research was designed to (1) investigate the number and size of Caspian tern colonies on the Columbia Plateau, and their relative dependence on juvenile salmonids as a food source compared to colonies in the Columbia River estuary, (2) determine the nature of the trade-off between nesting density and breeding success in order to provide guidelines for minimum area requirements for Caspian terns nesting at managed colony sites, and (3) estimate the number of juvenile salmonids consumed by Caspian terns nesting at the largest colony on the

Columbia Plateau, as well as examine how tern predation is directed at juvenile salmonids near this mid-Columbia River colony.

Chapter 2

BREEDING ECOLOGY OF CASPIAN TERNS AT COLONIES
ON THE COLUMBIA PLATEAU

Michelle Antolos, Daniel D. Roby, and Ken Collis

ABSTRACT

We investigated the breeding ecology of Caspian terns (*Sterna caspia*) nesting at colonies on the Columbia Plateau in southeastern Washington and northeastern Oregon. We surveyed the region to determine the status and size of known colonies, and focused research at colonies where Caspian terns foraged on juvenile salmonids (*Oncorhynchus* spp.) because of potential impacts to ESA-listed stocks. We estimated colony size, nesting density, fledging success, and diet composition in 2000 and 2001, and examined trends in colony size and area during 1996-2001. Colony size ranged from tens of breeding pairs to nearly 700 pairs. All Caspian tern colonies in the study area were associated with larger gull (*Larus* spp.) colonies, which may limit tern colony area. Mink (*Mustela vison*) predation caused complete abandonment of a tern colony of 275 pairs in 2000, which was not re-colonized in 2001. A new colony site was discovered on an island in Potholes Reservoir, Washington, where Caspian terns commuted over 50 km to the Columbia River to forage on juvenile salmonids. At colonies on the mid-Columbia River, the majority of Caspian tern prey items consisted of juvenile salmonids. High nesting densities at mid-Columbia River colonies suggest that availability of breeding habitat may have limited colony size. Fledging success varied dramatically among tern colonies and was lowest where nest predation was a factor. The size and number of Caspian tern colonies in the Columbia Plateau region are likely constrained by the availability of suitable nesting habitat near abundant prey, a resource that appears limited within the study area.

INTRODUCTION

We investigated the status, size, and ecology of Caspian tern (*Sterna caspia*) breeding colonies in the Columbia Plateau region of southeastern

Washington and northeastern Oregon, with emphasis on colonies in the mid-Columbia River. One impetus for this research was to evaluate the impact of Caspian tern predation on survival of juvenile salmonids (*Oncorhynchus* spp.) migrating down the Columbia River. In 1996, federal agencies were directed to investigate avian predation on juvenile salmonids in the lower and mid-Columbia River (NMFS 1995), because of potential impacts to evolutionarily significant units (ESUs) of salmonids listed as threatened or endangered under the U.S. Endangered Species Act (ESA). Caspian terns breeding at Rice Island in the Columbia River estuary were of particular concern because this large and growing colony had a high proportion of juvenile salmonids in the diet (Collis et al. 2002a).

Research initiated in 1997 by Oregon State University, the Columbia River Inter-Tribal Fish Commission, and the U.S. Geological Survey demonstrated that Caspian terns nesting on Rice Island consumed an estimated 9.1-15.7 million juvenile salmonids during the 1998 migration year (approximately 13% of the number of juvenile salmonids to reach the estuary; Roby et al. 2003). Shortly thereafter the decision was made to manage this tern colony in order to reduce its impact on survival of juvenile salmonids (USACE 1999). This management plan involved relocating Caspian terns nesting at Rice Island to an historic breeding site on East Sand Island, 26 km down-river, where terns were expected to consume fewer salmonids (Roby et al. 2002). One concern in implementing this management plan was the possibility that displacing terns from the Rice Island colony would cause terns to disperse to up-river colonies, where impacts on survival of juvenile salmonids might be as great or greater.

Data on Caspian tern colony size and diet in the mid-Columbia River were collected in 1997 and 1998, before management of terns was initiated in the Columbia River estuary. During those two years, the only two colonies of Caspian terns on the mid-Columbia River were on Crescent and Three Mile

Canyon islands. These colonies were much smaller than the Rice Island colony, but the diet of terns nesting at Three Mile Canyon Island consisted of a higher proportion of salmonids than that of terns nesting at Rice Island (Collis et al. 2002a). In part to address concerns about changes to the number and size of up-river tern colonies following tern management in the estuary, we conducted focused research on the status, size, and breeding ecology of Caspian tern colonies on the mid-Columbia River in 2000 and 2001. In addition, we made detailed observations of Caspian tern diet at these colonies in order to help gauge the magnitude of tern predation on juvenile salmonids. These data can be used to calculate estimates of salmonid consumption using bioenergetics models (see Chapter 4), and will help inform decisions on management of terns at these colonies by state, federal, and tribal resource managers.

While our research focused primarily on tern colonies in the mid-Columbia River, where terns were suspected to forage primarily on juvenile salmonids, we also investigated all known Caspian tern colonies on the Columbia Plateau. By doing so, we sought to comprehensively analyze the status of Caspian terns in the region, and to address factors controlling the number and size of tern colonies within the study area. This information may assist in long-term management of this sub-population, as well as contribute to demographic analyses of the Pacific Coast population of Caspian terns (e.g., Wires and Cuthbert 2000, Shuford and Craig 2002).

The first nesting records for Caspian terns in the Columbia Plateau region were in the early 1930s, when a single nest was found on an island in Moses Lake, WA (Kitchin 1930) and a colony of about 50 pairs was found on an island in the mid-Columbia River in Benton County, WA (Decker and Bowles 1932). The Moses Lake colony disappeared in the mid-1950s, and has since been replaced by a colony in Potholes Reservoir, WA, which formed after the reservoir was created in the late 1950s (G. Alcorn, pers. comm., cited in Penland 1982).

The Potholes Reservoir colony has fluctuated in numbers and changed nesting sites several times (Penland 1982); in 1997 there were three colonies on three different islands totaling 259 breeding pairs (Finger and Tabor 1997). In 1975, Penland (1982) observed five pairs of Caspian terns nesting on Cabin Island in the mid-Columbia River, just above Priest Rapids Dam. Thompson and Tabor (1981) thoroughly surveyed the Columbia River between Priest Rapids, WA and Portland, OR in 1977 and 1978, and while no Caspian tern colony was found in Benton County, WA, a colony of approximately 200 pairs was discovered on Three Mile Canyon Island, near Boardman, OR. Crescent Island, located in the Columbia River near Wallula, WA was created in 1985 from dredge-spoil as a nesting site for waterfowl, and was soon after colonized by Caspian terns (Ackerman 1994).

Our objectives in this study were (1) to test the hypothesis that management of the Caspian tern colony on Rice Island resulted in increased numbers of Caspian terns nesting at colonies in southeastern Washington and northeastern Oregon, (2) to identify factors controlling the number, size, and productivity of Caspian tern colonies in the Columbia Plateau region, and (3) to determine whether Caspian terns nesting at colonies in the mid-Columbia River were more dependent on juvenile salmonids as a food source than terns nesting in the Columbia River estuary.

METHODS

STUDY AREA

This study was conducted at Caspian tern colonies located on the Columbia Plateau in southeastern Washington and northeastern Oregon (Figure 2.1). Sites where historical records of Caspian tern nesting existed, or where nesting was suspected, were checked throughout this area in 2000. The

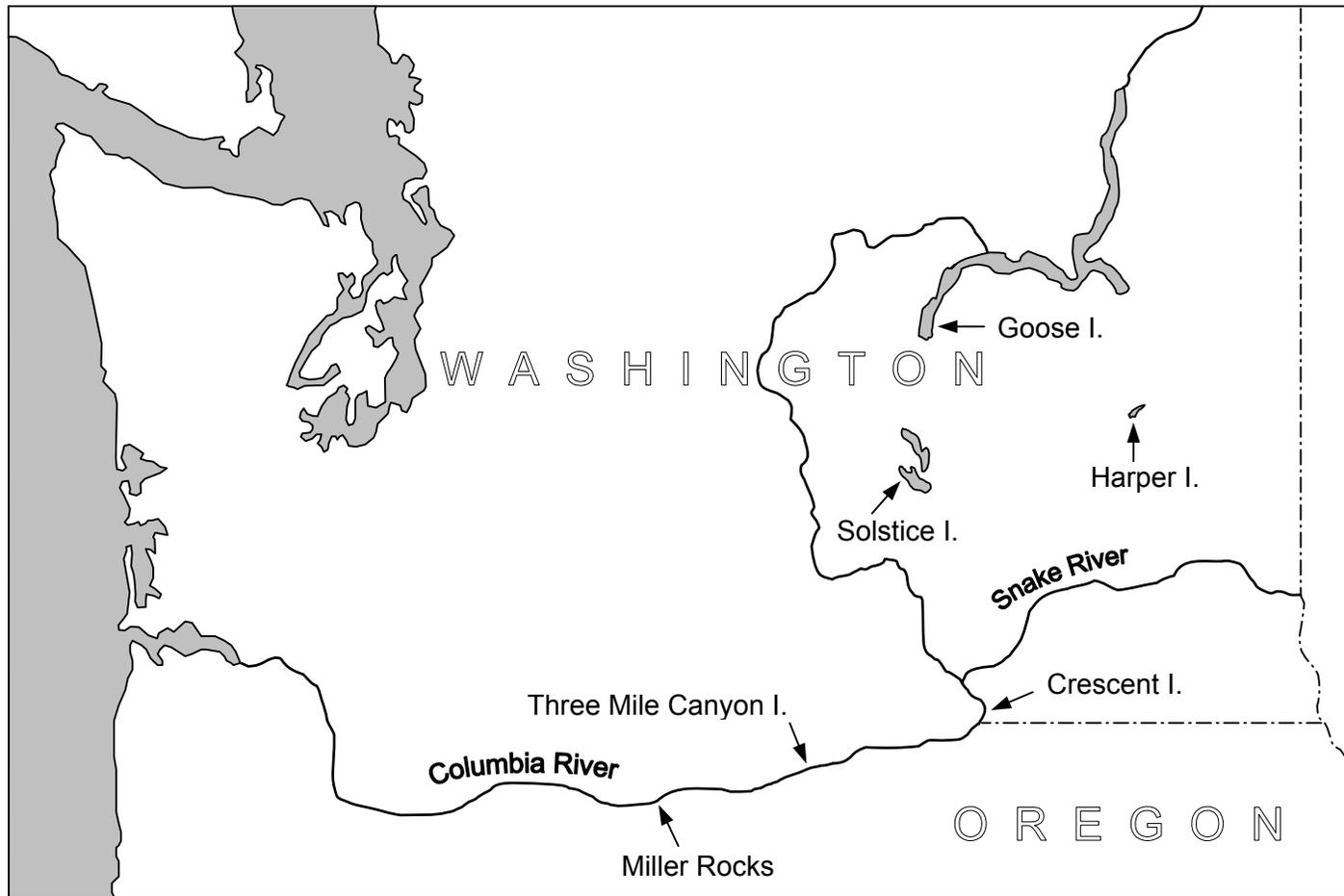


Figure 2.1. Locations of known Caspian tern colonies in the Columbia Plateau region of southeastern Washington and northeastern Oregon during 2000-2001.

information gained from this survey directed our research efforts in 2001. Research was focused mainly on three colonies: Crescent Island (46.094°N, 118.929°W), Three Mile Canyon Island (45.817°N, 119.963°W), and Solstice Island (47.023°N, 119.353°W), with limited investigations at Goose Island (47.649°N, 119.290°W), Harper Island (47.248°N, 118.085°W), and Miller Rocks (45.662°N, 120.875°W).

Crescent Island is a comma-shaped dredge-spoil island of 3.2 ha located in the McNary Pool of the Columbia River. It is low-lying and flat, and its substrate consists of sand, gravel, and cobble, with a rip-rap perimeter. The center of the island is densely vegetated (see Ackerman 1994 for a description), and there was a large colony of California gulls (*Larus californicus*) and a small number of ring-billed gulls (*L. delawarensis*) nesting on the island. The California gull colony nearly surrounded the Caspian tern colony on the northeastern side of the island.

Three Mile Canyon Island is 7.2 ha and is located in the John Day Pool of the Columbia River. California and ring-billed gulls nested in large numbers throughout the island, wherever woody vegetation was sparse. The Caspian tern colony was located on the northeastern end of the island, in a sandy clearing, where a small number of California gulls nested on the edge of the tern colony. The island is sandy and rocky, with abundant grasses, shrubs, and trees, and a rip-rap spine extending outward at the eastern and western ends of the island.

Solstice Island, located at the north end of Potholes Reservoir, is mostly sandy and only partially vegetated, and the Caspian tern colony was located on a large dune on the eastern edge of the island. The island is 1.6 ha in area and supported a mixed colony of California and ring-billed gulls, which partially bordered the Caspian tern colony.

Goose Island is approximately 0.2 ha and is located in Banks Lake, Washington. It is the northernmost of a small group of islands at the south end of the lake. The substrate is basalt rock, with very little sediment or vegetation, and

Caspian terns nested among California and ring-billed gulls on the southern portion of the island.

Harper Island, in Sprague Lake, Washington, is a partially vegetated basalt rock island of 13 ha with steep sides and a flat top. California and ring-billed gulls nested in large numbers on this island and bordered the Caspian tern colony, located on the northwestern edge of the island.

Miller Rocks, a cluster of basalt rock islets, is located in the reservoir formed by The Dalles Dam in the Columbia River, northeast of Miller Island, Washington. Caspian terns nested among California and ring-billed gulls on the westernmost of the two main islets, which has an area of approximately 0.4 ha.

COLONY SIZE

Colony sizes were estimated using several methods. Aerial photographs were taken with a high resolution (1:1200), large format camera (Zeiss RMK Top 300) during late incubation, when maximum colony attendance was assumed (Bullock and Gomersal 1981, Gaston and Smith 1984). Photographs were taken annually of Crescent Island and Three Mile Canyon Island during 1996-2001, and of Solstice Island in 2001. Direct counts of total numbers of Caspian terns and gulls were made from these photographs by the Survey, Mapping, and Photogrammetry Department of the Bonneville Power Administration (Portland, Oregon). Gulls counted included both California and ring-billed gulls, which could not be distinguished on the aerial photos. These data were then used to assess trends in colony size across years for both terns and gulls at Crescent and Three Mile Canyon islands. More details on these aerial photo censusing methods are provided in Collis et al. (2002a). At Solstice Island in 2000, Miller Rocks in 2001, and Goose and Harper islands in both years, estimates of tern colony size were based on ground counts obtained off-colony or from the water.

The number of breeding pairs at colonies on Crescent, Three Mile Canyon, and Solstice islands was also estimated. Correction factors were used to convert the total numbers of Caspian terns counted on the aerial photos to estimates of the numbers of breeding pairs. Ratios of the number of incubating terns to the total number of terns in sampled areas of the colony were determined either by counting birds in 5m x 5m plots from observation blinds (Crescent Island in 2000 and 2001; N = 16 plots, Three Mile Canyon Island in 2000; N = 5 plots) or by conducting multiple counts of a portion of the colony from the water (Solstice Island in 2001; N = 6 counts). These correction factors were determined on the day of aerial photography (Crescent and Three Mile Canyon islands) or the day before aerial photography (Solstice Island), then multiplied by the total number of terns counted from the aerial photographs, and averaged to obtain a final estimate of the number of breeding pairs (referred to as the AERIAL count).

At Crescent Island in 2000 and 2001, the total number of incubating birds on the colony was also counted directly from an observation blind at the time of aerial photography, in order to verify the accuracy of the AERIAL count. This allowed us to compare a direct ground count of the number of breeding pairs (the GROUND count) to the estimate obtained using the AERIAL method, both of which estimated the number of breeding pairs on a single day in late incubation. GROUND counts were not made at Three Mile Canyon Island or at Solstice Island, because not all Caspian tern nests were in view of our observation points at the time of aerial photography.

The total number of nesting attempts was also estimated at Crescent Island in 2000 and 2001 using a STAGGERED count which included nests that may have been initiated after the one-time GROUND count. A large grid of 5m x 5m sample plots was placed on the Caspian tern colony before the initiation of egg laying, so that most of the colony was within the grid. At least once a week, the number of incubating birds both within and outside the 5m x 5m sample plots was

counted ($N = 16$ plots, $N = 12$ areas outside the plots). When the number of incubating birds in each of these areas reached a maximum, this value was taken to be the final number of breeding pairs in that area. The maximum counts of incubating birds from each area were then summed to yield a grand total of breeding attempts for the colony. Thus the STAGGERED count included nests initiated late in the breeding season, after the time of the aerial photograph. Because the STAGGERED count may include re-nesting attempts by pairs that moved to new areas of the colony after an initial nest failure, we refer to the STAGGERED count as an estimate of the total number of breeding attempts, rather than the number of individual pairs nesting at the colony.

NESTING DENSITY

Nesting density of Caspian terns was only determined for those colonies and years for which aerial photographs were taken and estimates of breeding pairs were made. The estimate of breeding pairs from the AERIAL count was divided by the area of the colony, as determined from the aerial photographs using Plus3 TerraModel software. This measure of nest density could be compared among all colonies and years with aerial photography and estimates of breeding pairs. We also calculated nest density at Crescent Island in 2000 and 2001 using the GROUND counts, in order to present our best estimate of overall nesting density. Colony areas from aerial photography were also used to examine trends in tern colony area, and thus nesting habitat, at Crescent and Three Mile Canyon islands between 1996 and 2001.

FLEDGING SUCCESS

Nest success was determined at Crescent, Three Mile Canyon, and Solstice islands by counting the total number of chicks on-colony approximately one week after the first chick fledged and dividing by the estimated number of

breeding pairs. The AERIAL count of breeding pairs was used for these calculations, so that fledging success could be compared among colonies. We assumed that at this stage of the fledging period the number of young that had already fledged and left the colony would equal the number of chicks counted on-colony that would not survive to fledge. We also calculated estimates of fledging success at Crescent Island based on GROUND counts of breeding pairs in order to present our best estimates of overall fledging success.

DIET COMPOSITION

Diet composition (percent of prey items belonging to various prey types) was determined for Caspian terns nesting at Crescent, Three Mile Canyon, and Solstice islands. Prey items were visually identified to the lowest distinguishable taxa by observing bill loads of adult terns (fish held crosswise in the bill) at the colony from observation blinds or from the water (see Collis et al. 2002a). Approximately 100-200 tern bill loads were identified each week at Crescent Island in 2000 and 2001, while at Three Mile Canyon Island in 2000 and Solstice Island in 2001 approximately 250-300 bill loads were identified over the entire breeding season. A total percentage of each prey type in the diet for each colony-year was then calculated by taking the average of the weekly percentages. This method was employed in order to avoid a bias towards weeks with high sample sizes; sample sizes varied among weeks and diet composition was variable throughout the season (see Figure 2.5). Fates of individual fish (i.e., fed to an adult tern, fed to a chick, or kleptoparasitized by a gull) were also recorded so that we could assess relative kleptoparasitism pressure from gulls among colonies and years.

STATISTICAL ANALYSIS

We examined potential trends in the number of terns and gulls nesting at Crescent and Three Mile Canyon islands by log-transforming counts and then regressing total numbers on year. Simple linear regression was also used to examine trends in tern colony area over time. We tested for differences in diet composition using Chi-squared tests for independence. All reported *P*-values are two-sided.

RESULTS

COLONY STATUS

We did not find Caspian terns nesting at Cabin Island above Priest Rapids Dam, nor did we find any Caspian tern colonies in Benton County, WA (although this area was not searched in its entirety). In 2000, a single Caspian tern colony was found on a small island at the north end of Potholes Reservoir (47.023°N, 119.353°W), dubbed Solstice Island by the authors. Researchers first observed Caspian terns nesting among gulls on Miller Rocks in 2001 (D.P. Craig, Willamette University, pers. comm.). The colonies on Goose Island in Banks Lake and on Harper Island in Sprague Lake were previously known Caspian tern nesting sites (see Shuford and Craig 2002). Therefore, Solstice Island and Miller Rocks were the only new colonies in the study area discovered in 2000 and 2001. These four colonies, plus the colonies on Crescent and Three Mile Canyon islands, were the only known nesting sites for Caspian terns in the Columbia Plateau region (southeastern Washington and northeastern Oregon) in 2000 and 2001, although other small colonies may have been missed. Because we were most interested in investigating sites where Caspian terns foraged on juvenile salmonids, the bulk of our research effort was focused on Crescent and Three Mile Canyon islands, where preliminary studies suggested that the proportion of

juvenile salmonids in the diet of terns was high (Collis et al. 2002a). We initiated collection of data on diet and number of breeding pairs at the Solstice Island Caspian tern colony in 2001, after it was discovered in 2000 that terns from this colony were making exceptionally long trips to the mid-Columbia River to forage on juvenile salmonids (see Diet Composition).

COLONY SIZE

The numbers of Caspian terns counted at each colony in the study area between 1996 and 2001 are presented in Table 2.1. Although not all of these counts were conducted using the same methods (aerial photos were not taken of Goose Island, Harper Island, Miller Rocks, or Solstice Island in 2000 and these counts were conducted much later in the breeding season than for other colony-years), the counts demonstrate the large range in size of Caspian tern colonies in the region. Crescent Island was the largest known Caspian tern colony in the study area, followed by Three Mile Canyon and Solstice islands, with much smaller numbers nesting at Goose Island, Harper Island, and Miller Rocks.

There was no significant change in the size of the Crescent Island tern colony between 1996 and 2001 ($P = 0.16$, from a simple linear regression); however, counts from aerial photographs have fluctuated considerably (Figure 2.2a). At Three Mile Canyon Island, the size of the tern colony did not change significantly between 1996 and the initial stages of the 2000 breeding season ($P = 0.45$; Figure 2.2b). By early chick-rearing in 2000, however, all Caspian terns nesting on Three Mile Canyon Island had abandoned this site. During the 2000 nesting period we observed incubating adult terns at the Three Mile Canyon Island colony flushing at a high frequency, leading us to suspect predator activity. During the night of 5 June 2000, we observed a mink (*Mustela vison*) on the colony, and this nocturnal disturbance caused adult terns to abandon their nests until sunrise. Young tern chicks are unable to thermoregulate efficiently on their

Table 2.1. Total numbers of Caspian terns (*Sterna caspia*) counted on-colony for six breeding colonies in the Columbia Plateau region of southeast Washington and northeast Oregon. Unless noted otherwise, these numbers were determined from aerial photography taken on 5 June 1996, 20 May 1997, 22 May 1998, 28 May 1999, 22 May 2000, and 21 May 2001. ND = no data.

SITES	1996	1997	1998	1999	2000	2001
Crescent Island	347	941	636	677	870	904
Three Mile Canyon Island	436	526	349	418	431	1
Solstice Island	ND	ND	ND	ND	199 ¹	368
Goose Island	ND	ND	ND	ND	30 ²	29 ³
Harper Island	ND	ND	ND	ND	32 ⁴	33 ⁵
Miller Rocks	0	0	0	ND	ND	13 ⁶

Determined from ground counts on: ¹20 June, ²29 June, ³27 June, ⁴8 July, ⁵2 July, ⁶17 June; 32 adults were counted on 7 June (D.P. Craig, Willamette University, pers. comm.).

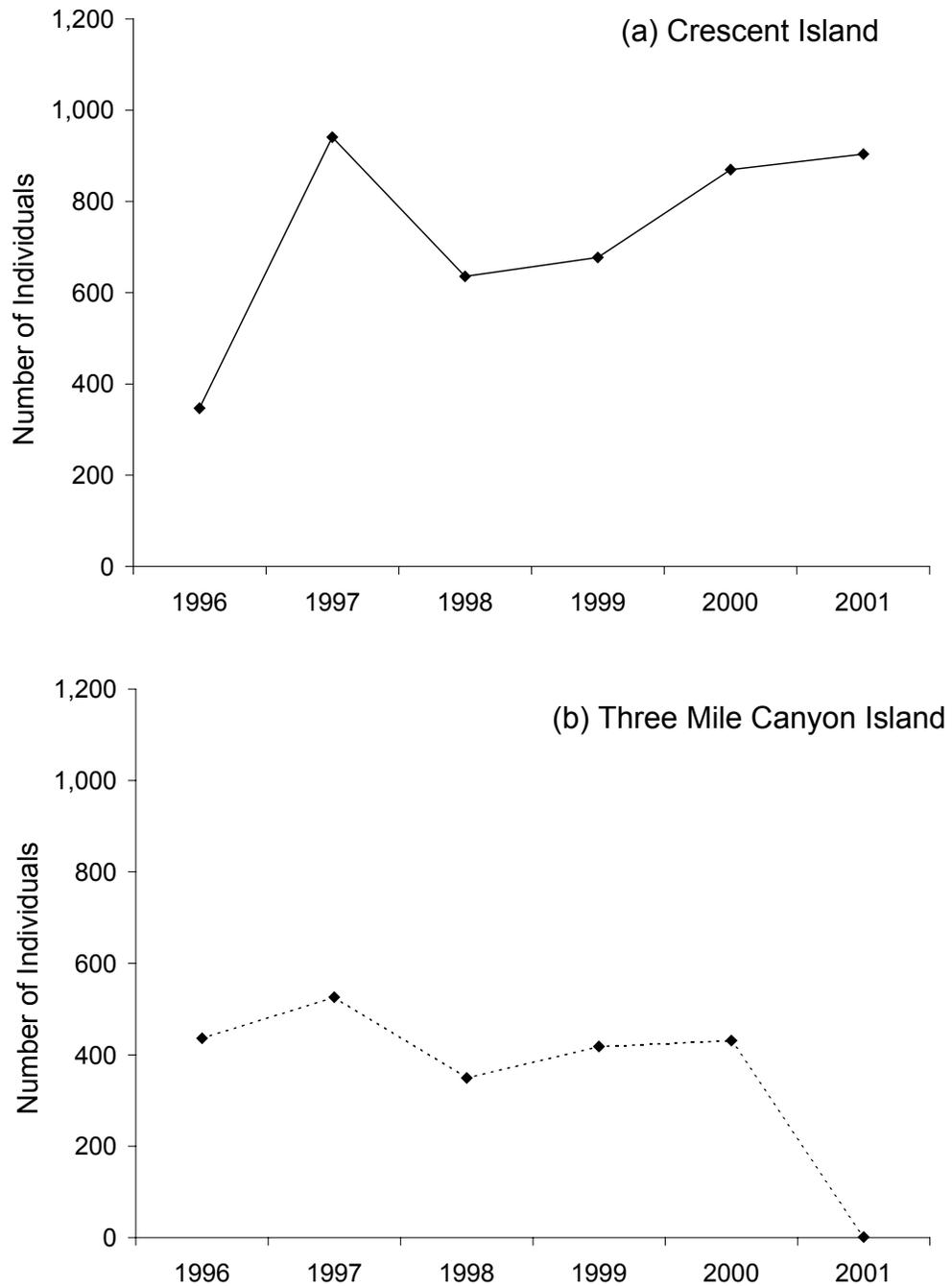


Figure 2.2. Total number of Caspian terns counted from aerial photography of the Crescent Island colony (a) and Three Mile Canyon Island colony (b), 1996-2001.

own, and often cannot survive prolonged abandonment by adults (Cuthbert and Wires 1999). A combination of such indirect effects of mink disturbance and direct mink predation on eggs and chicks likely caused the total nesting failure at the colony. Early in the 2001 breeding season, we found considerable evidence of mink activity, including a number of carcasses of depredated California and ring-billed gulls. Only two Caspian tern nests were known to have been initiated on Three Mile Canyon Island in 2001; the contents were quickly depredated by California gulls. After these initial nesting attempts, Caspian terns did not attempt to nest on Three Mile Canyon Island in 2001, presumably because of mink activity. Within a month, very few Caspian terns were seen roosting at the colony site (Figure 2.2b).

The numbers of gulls counted from aerial photography during late incubation on Crescent and Three Mile Canyon islands are presented in Table 2.2. There was no significant trend in the number of gulls present on Crescent Island, or Three Mile Canyon Island between 1996 and 2001 ($P = 0.47$, $P = 0.45$, respectively; Figure 2.3). While we did not detect an increase in the number of gulls nesting on these two islands, we examined the trend in Caspian tern colony area at Crescent and Three Mile Canyon islands to evaluate whether gulls might be limiting or encroaching on tern nesting habitat. There was no significant change in the area of the Caspian tern colony on Crescent Island between 1996 and 2001 ($P = 0.11$; Figure 2.4); however, there was a significant increase in tern colony area when 1998 was excluded from the analysis ($P = 0.03$). The area of the tern colony at Three Mile Canyon Island decreased significantly between 1996 and 2000 ($P = 0.02$), before the abandonment of the colony in June of 2000 (Figure 2.4).

In 2000 and 2001, the number of Caspian terns nesting at Crescent Island was roughly double the number of breeding terns at Three Mile Canyon Island at the start of the 2000 breeding season, and at Solstice Island in 2001 (Table 2.3).

Table 2.2. Total numbers of California and ring-billed gulls (*Larus californicus* and *L. delawarensis*) counted on islands in the Columbia Plateau region from aerial photography taken during late incubation, 1996-2001. ND = no data.

SITES	1996	1997	1998	1999	2000	2001
Crescent Island	3,334	5,769	4,597	4,929	4,262	2,690
Three Mile Canyon Island	8,828	13,305	11,102	9,338	9,573	8,836
Solstice Island	ND	ND	ND	ND	ND	4,297

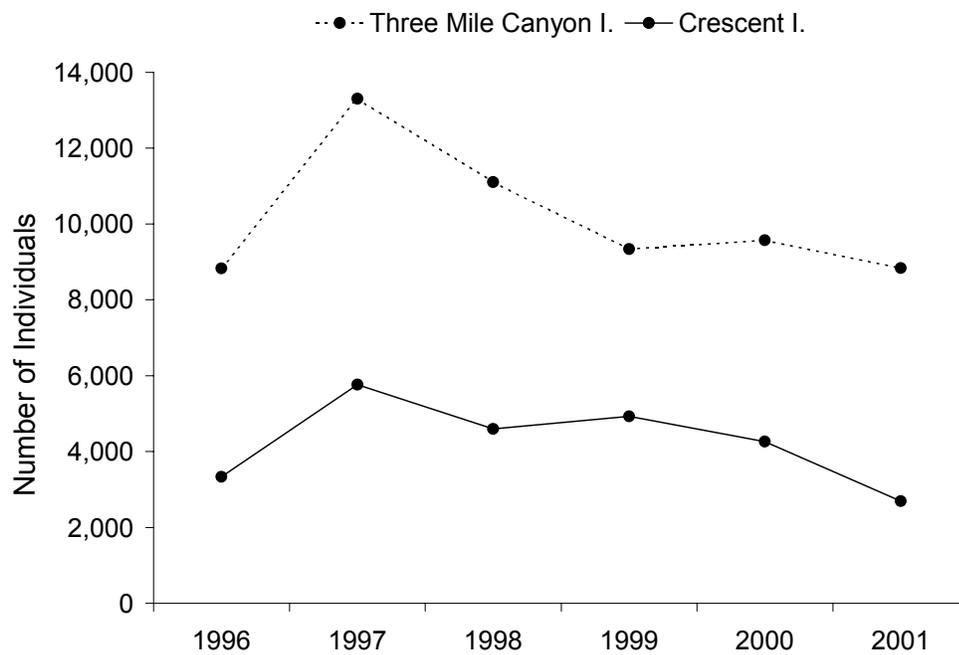


Figure 2.3. Total number of gulls (California and ring-billed) counted from aerial photography of Three Mile Canyon and Crescent islands, 1996-2001.

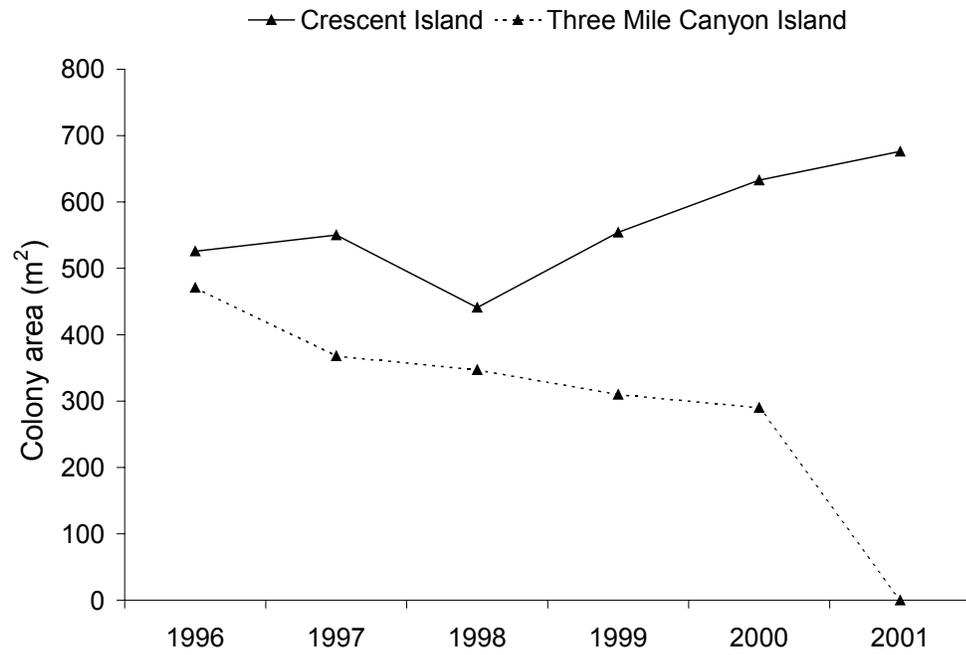


Figure 2.4. Area of Caspian tern colonies on Crescent and Three Mile Canyon islands during late incubation, 1996-2001.

Table 2.3. Comparison of three methods of determining size of Caspian tern colonies in the Columbia Plateau region: one-time estimates of the number of breeding pairs determined from AERIAL photography (Mean \pm SE) or from GROUND counts, and STAGGERED counts of the total number of nesting attempts, including those initiated after the one-time census.

	Crescent Island		Three Mile Canyon Island	Solstice Island
	2000	2001	2000	2001
AERIAL	548 \pm 9.8	657 \pm 11.7	275 \pm 3.7	138 - 248
GROUND	548	688		
STAGGERED	571	720		

The estimated number of breeding pairs based on the AERIAL count was the same as the estimate from the GROUND count for the Crescent Island tern colony in 2000; however, the estimate from the GROUND count was 4.7% greater than the estimate from the AERIAL count at Crescent Island in 2001 (Table 2.3). In this case, we believe the GROUND count was a more accurate estimate of the number of breeding pairs because it was a direct, colony-wide count of incubating terns. Therefore, we considered the GROUND count our best estimate of the number of breeding pairs and used it to calculate our best estimate of nesting density and fledging success at Crescent Island. We used estimates generated from the AERIAL counts when making comparisons among colonies and years.

We also compared the estimated number of breeding pairs from the AERIAL count to the estimated number of breeding attempts from the STAGGERED count at Crescent Island in 2000 and 2001. The estimate generated from the AERIAL count underestimated the total number of breeding attempts in both years, by 4.0% in 2000 and by 8.8% in 2001. This difference is because the STAGGERED count includes nests not yet initiated at the time of the aerial photograph, as well as re-nesting attempts. Because we could not distinguish re-nesting attempts from late nesters, we did not use these estimates to calculate fledging success; however, they are useful for estimating the number of nests initiated at Crescent Island during the two years of study.

The correction factor used to estimate number of breeding pairs from the number of terns counted in the aerial photograph of Solstice Island in 2001 (AERIAL count) was much smaller than those calculated at Three Mile Canyon and Crescent islands, and thus we suspect this estimate may not have been accurate. This may have been due to difficulties in counting the number of incubating versus attending terns at Solstice Island. All counts were made from the water, and not from an observation blind, thus visibility was limited. In addition, it was not possible to lay out a grid on the colony in order to assist with

counts. Because of these potential inaccuracies, we present the results for the number of tern breeding pairs at Solstice Island as a range, the lower value derived from the original correction factor, and the upper value derived from an average of the correction factors determined at the other two colonies (Table 2.3).

NESTING DENSITY

Overall densities of tern nests at colonies on Crescent and Three Mile Canyon islands were similar, and higher than tern nest densities at Solstice Island (Table 2.4). Nest density increased in association with an increase in colony size at Crescent Island; nest density increased 17.2% from 2000 to 2001, concurrent with a 25.5% increase in colony size (based on our best estimates of nesting density and number of breeding pairs at Crescent Island; Table 2.4).

FLEDGING SUCCESS

No young terns were fledged from the Three Mile Canyon Island colony in either 2000 or 2001 due to predation and disturbance by mink. At Crescent Island, we estimated that 368 chicks fledged in 2000 and 703 chicks fledged in 2001. We used the estimates of the number of breeding pairs from the AERIAL method to calculate overall fledging success (Table 2.4), and the number of breeding pairs from the GROUND method to calculate our best estimates of fledging success at Crescent Island. These estimates were the same in 2000, and differed by 4.7% in 2001. When making comparisons among Caspian tern colonies in general, we used overall fledging success determined from the AERIAL count. Estimated fledging success at Solstice Island in 2001 was imprecise, but apparently high.

Table 2.4. Colony size, nesting density, and fledging success of Caspian tern colonies in the Columbia Plateau region, with data from colonies in the Columbia River estuary for comparison. All estimates based on AERIAL method (best estimates in parenthesis based on GROUND counts).

	Columbia Plateau				Columbia River estuary				
	Crescent Island		Three Mile Canyon Island	Solstice Island	Rice Island ¹		East Sand Island ¹		
	2000	2001	2000	2001	1999	2000	1999	2000	2001
Breeding pairs	548 (548)	657 (688)	275	138-248	8,300	590	550	8,500	8,900
Nesting density (pairs/m ²)	0.87 (0.87)	0.97 (1.02)	0.95	0.41-0.74	0.78	0.25	0.26	0.62	0.57
Fledging success (fledglings/pair)	0.67 (0.67)	1.07 (1.02)	0.00	1.04-1.88	0.55	0.15	1.20	0.57	1.40

¹From Roby et al. 2002

DIET COMPOSITION

We initiated collection of diet data at the Solstice Island colony in 2001 because we discovered that terns nesting at this site were commuting long distances to the Columbia River to forage on juvenile salmonids. Caspian terns were observed more than 50 km from Potholes Reservoir foraging at mid-Columbia River dams (Priest Rapids, Wanapum, Rocky Reach, and Rock Island dams) in 2000 (C. Thompson, WDFW, pers. comm.). We suspected these terns were nesting in Potholes Reservoir because we were unable to find a Caspian tern colony in closer proximity to these dams and we found clear evidence that terns nesting on Solstice Island were foraging on juvenile salmonids in the Columbia River.

We observed Caspian terns transporting juvenile salmonids back to the Solstice Island colony (21.8% of N = 55 identified prey items in bill loads) in late June 2000. We also found numerous passive integrated transponders (PIT tags), radio tags, and acoustic tags from juvenile salmonids on the Solstice Island tern colony. These tags were first discovered during banding of tern chicks on 7 July 2000, and then after the breeding season (26 July 2000), when over 1,700 tags were collected. This included 1,218 PIT tags from juveniles salmonids tagged as part of a survival study at Wells Dam, WA, representing 2% of all PIT-tagged smolts released in the study (S. Bickford, Douglas County PUD, pers. comm.). The large number of salmonid tags recovered at Solstice Island was surprising because it demonstrated that terns nesting on Solstice Island frequently made long-distance foraging trips (> 100 km round-trip) to the mid-Columbia River to forage on juvenile salmonids. In addition, all tags recovered were from the 2000 salmonid migration year, suggesting that Solstice Island may have been a new nesting site for Caspian terns in 2000, or that terns nesting on Solstice Island did not make frequent foraging trips to the mid-Columbia River before the 2000 breeding season.

We analyzed diet data during two different sampling periods in order to permit comparison of the proportion of juvenile salmonids in the diet of Caspian terns nesting at Crescent, Three Mile Canyon, and Solstice islands. Because we were only able to collect diet data at the Three Mile Canyon Island colony from the beginning of May until mid-June, when Caspian terns abandoned the site, diet comparisons to other colonies only included observations during this time period. Otherwise, diet data from the entire breeding season (late April-late July) were used for comparisons. It was necessary to compare diet data from similar time periods because the proportion of salmonids in the diet of Caspian terns declined as the breeding season progressed (Figure 2.5), presumably because the number of out-migrating juvenile salmonids in the Columbia River also declined as the season progressed (FPC 2003).

Caspian terns nesting at the Three Mile Canyon Island colony in 2000 had a higher proportion of juvenile salmonids in the diet compared to those nesting on Crescent and Solstice islands (Table 2.5). This difference was significantly greater when compared to the Crescent Island colony in 2000 ($\chi^2_1 = 5.22$, $P = 0.02$) and the Solstice Island colony in 2001 ($\chi^2_1 = 106.47$, $P < 0.0001$), but was not significantly different from the Crescent Island colony in 2001 ($\chi^2_1 = 0.511$, $P = 0.47$). At Crescent Island, the proportion of salmonids in the diet was significantly greater in 2001 compared to 2000 ($\chi^2_1 = 13.63$, $P = 0.0002$). Salmonids did not comprise the majority of the diet of Caspian terns nesting at Solstice Island in 2001 (Table 2.5), but the prevalence of salmonids in the diet during the 2001 breeding season provides additional evidence that long-distance foraging trips to the Columbia River were not rare events for terns using this colony.

Other prevalent prey items in the diet of Caspian terns nesting on Crescent, Three Mile Canyon, and Solstice islands were bass (*Micropterus* spp.),

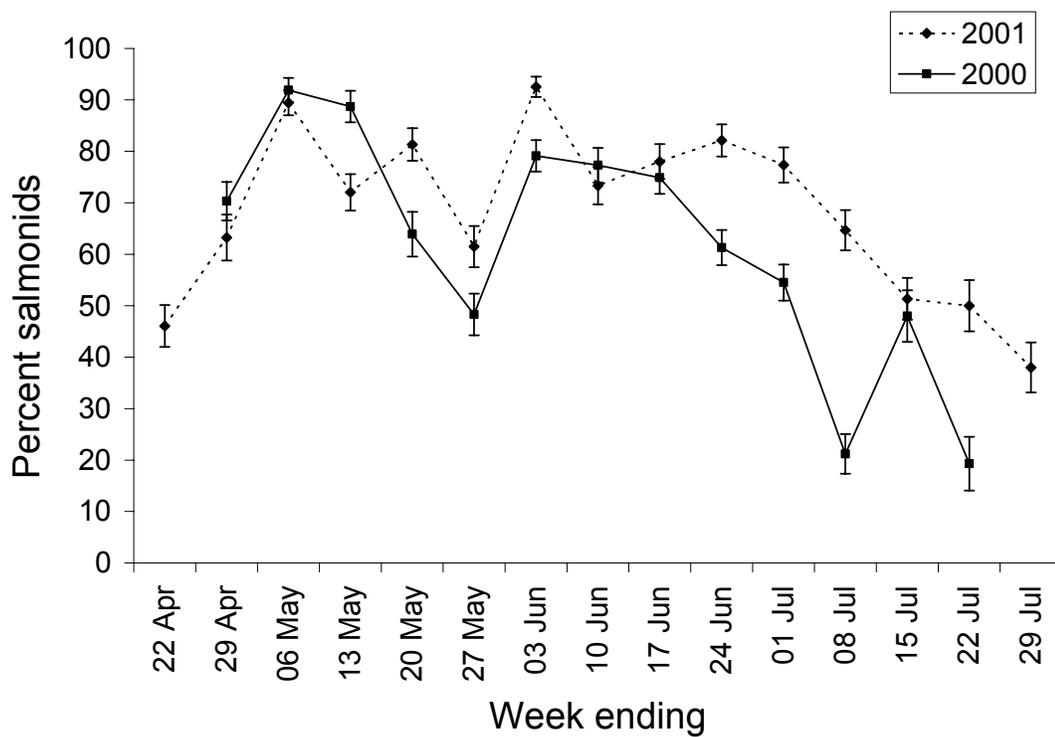


Figure 2.5. Proportion of juvenile salmonids in the diet of Caspian terns nesting on Crescent Island in 2000 and 2001 by week. Diet composition was based on visual identification of tern bill loads from a blind next to the colony. Error bars represent standard error.

Table 2.5. Proportion of juvenile salmonids in the diet (average of weekly percentages of identified prey items) of Caspian terns nesting at colonies in the Columbia Plateau region.

	Crescent Island		Three Mile Canyon Island	Solstice Island
	2000	2001	2000	2001
% salmonids in diet (entire season)	61.4 (N = 1,855)	68.1 (N = 2,164)	---	26.9 (N = 255)
% salmonids in diet (May to mid-June)	74.9 (N = 846)	78.4 (N = 944)	85.8 (N = 331)	32.8 (N = 155)

bluegill (*Lepomis macrochirus*), peamouth (*Mylcheilus caurinus*), yellow perch (*Perca flavescens*), and suckers (*Catostomus* spp.; see Table 2.6).

OTHER OBSERVATIONS

Gull Kleptoparasitism

The proportion of fish delivered to the colony that were kleptoparasitized by gulls was greater at Crescent Island in 2000 (21.5%, N = 1,997) and in 2001 (16.7%, N = 1,960) than at Three Mile Canyon Island in 2000 (10.9%, N = 322) or at Solstice Island in 2000 (2.2%, N = 45) or 2001 (4.5%, N = 200). This reflects differences among colonies in the numbers of gulls nesting in close proximity to tern nests. At Crescent Island, California gulls nearly surrounded the Caspian tern colony, while smaller numbers of gull nests bordered the tern colonies at Three Mile Canyon and Solstice islands.

Nest Predators

The only evidence of mammalian predation at Caspian tern colonies in the study area was at Three Mile Canyon Island, where mink predation caused the abandonment of the Caspian tern colony in 2000, and also caused mortality to adult California and ring-billed gulls. We observed California gulls preying on tern eggs and chicks at Crescent and Three Mile Canyon islands, especially after disturbance events; gull nest predation rates at Crescent Island, however, were low (see Chapter 3). We did not observe predation of tern eggs or chicks by any other avian species, nor did we observe evidence of predation on adult terns at any of these colonies.

Interspecific Chick Adoption

We observed an instance of interspecific chick adoption at the Crescent Island Caspian tern colony in 2001. An adult Caspian tern was observed brooding

Table 2.6. Diet composition (average of weekly percentages of identified prey items in bill loads) of Caspian terns nesting at colonies in the Columbia Plateau region.

Prey Type	Crescent Island		Three Mile Canyon Island	Solstice Island
	2000	2001	2000	2001
Salmonid ¹	61.4	68.1	85.8	26.9
Bass, bluegill ²	12.2	11.6	5.60	36.5
Peamouth, pikeminnow, chiselmouth ³	6.13	9.97	0.28	2.00
Sucker ⁴	0.46	2.46	0.0	0.0
Sculpin ⁵	0.60	1.44	0.0	0.0
Yellow perch ⁶	1.17	1.32	0.41	9.89
Catfish ⁷	1.33	1.16	0.0	0.0
Sandroller ⁸	0.0	0.80	0.0	0.0
Lamprey ⁹	0.58	0.63	0.0	0.0
Unidentified non-salmonids	16.1	2.52	7.93	24.7

¹*Oncorhynchus* spp.; ²Centrarchidae; ³Cyprinidae; ⁴Catostomidae; ⁵Cottidae; ⁶Percidae; ⁷Ictaluridae; ⁸Percopsidae; ⁹Petromyzontidae

a California gull chick when it was approximately five days old on 28 May. The nest also contained two tern eggs, both of which later hatched, but we did not ascertain whether the gull was adopted as a chick (California gull chicks can leave the nest as early as day 4 post-hatch; Winkler 1996) or accidentally rolled into the nest scrape as an egg. We continued to monitor the nest, and while the earlier-hatching tern chick did not survive, the second tern chick and the gull chick both survived until at least 25 June. We observed adult Caspian terns feeding the gull chick on four occasions, and it was brooded and/or attended consistently while it remained at the nest scrape (Figure 2.6). We were unable to determine the final fate of the adopted gull chick because we could not monitor its survival once the adult terns ceased attending the original nest scrape.

DISCUSSION

The results presented here reflect the dynamic nature of Caspian tern colonies in the Pacific Northwest. The status and size of Caspian tern colonies changed both from historical records and during this study. There were no active Caspian tern colonies found in Benton County, WA, or on Cabin Island, although terns have been observed nesting at these sites in the past (Decker and Bowles 1932, Penland 1982). The colony at Three Mile Canyon Island was completely abandoned in 2000 after an apparently continuous history of nesting for at least 24 years (Thompson and Tabor 1981). Caspian terns nesting in Potholes Reservoir have a history of changing colony sites (Penland 1982, Finger and Tabor 1997), and in 2000, Caspian terns apparently colonized a new site on Solstice Island. Caspian terns were observed nesting for the first time on Miller Rocks in 2001 (D. P. Craig, Willamette University, pers. comm.). Miller Rocks was surveyed in 1977 and 1978 by Thompson and Tabor (1981), and during 1996-1998 by the



Figure 2.6. Adult Caspian tern attending an adopted California gull chick (on right) and its own chick (below) on Crescent Island, 2001.

authors, but Caspian terns were not observed nesting at this site during those years.

Our results also suggest that Caspian tern colonies within the study area may remain stable in size for an extended period, and then experience dramatic change. The size of the Crescent Island colony did not change significantly during 1996-2001; however, the number of breeding pairs at Crescent Island during the time period of this study was approximately 5-7 times greater than that estimated in 1993 (100 pairs; Ackerman 1994). The size of the Three Mile Canyon Island tern colony had apparently remained relatively stable between the late 1970's (approximately 200 pairs; Thompson and Tabor 1981) and the start of the 2000 breeding season (275 pairs), until predation and disturbance by mink caused complete abandonment of the colony in June of 2000. The increase in colony size at Crescent Island in 2001 was likely related to the demise of the Three Mile Canyon Island colony, and suggests that changes in size of Caspian tern colonies may be related to predator activity and habitat changes at other colonies. Our study did not provide any evidence, however, that tern colonies in the mid-Columbia River increased as a result of the initiation of tern management in the Columbia River estuary in 1999. Colony size within our study area ranged from tens of pairs to nearly 700 breeding pairs. While this range encompasses much of the variability in colony size for Caspian terns, all colonies in the Columbia Plateau region were less than one-tenth the size of the East Sand Island Caspian tern colony in the Columbia River estuary during the same period (Roby et al. 2002; Table 2.4).

Colony area may also change over time at Caspian tern colonies. At Three Mile Canyon Island, tern colony area declined significantly during 1996-2000, suggesting that nesting gulls may have encroached on tern breeding habitat over time. Tern colony area did not change significantly at Crescent Island during the study period; however, there was a significant increase in tern colony area when

an anomalous year (1998) was removed from the analysis. This suggests that while gulls might limit expansion of tern colony area, they do not appear to be encroaching upon tern nesting habitat at this site. At Three Mile Canyon Island, while encroachment by nesting gulls may have caused a decline in tern colony area, mink predation was the ultimate cause of tern colony abandonment. Other studies have suggested that gull encroachment can cause abandonment of tern colonies (Crowell and Crowell 1946, Smith and Mudd 1978); however, these studies generally describe encroachment by gull species that are considerably larger than California and ring-billed gulls and commonly prey on tern eggs and chicks. While changes to tern colony area might also be caused by vegetation encroachment or changes in water level (e.g., water level can fluxuate by about 5 m in Potholes Reservoir; Finger and Tabor 1997), there was no direct evidence of these effects at colonies within our study area during the study period.

Nest density and fledging success varied among the colonies under study, and differed from other Caspian tern colonies in the Columbia River estuary. Crescent and Three Mile Canyon islands had higher nest densities than did colonies in the Columbia River estuary, while estimated nest density at Solstice Island was similar to that observed in the estuary (Roby et al. 2002; Table 2.4). At Crescent Island, nesting density increased with an increase in colony size from 2000 to 2001, suggesting that nesting densities may vary in accordance with availability of breeding habitat. Therefore, high nest densities at colonies in the mid-Columbia River may reflect constraints on breeding habitat at these sites. Similarly, lower nest density at Solstice Island suggests that the size of this colony may not be habitat-limited. Caspian terns nesting at this colony may, instead, be constrained by food availability. This is supported by our observations that terns nesting at Solstice Island regularly commuted over 50 km to the mid-Columbia River to forage on juvenile salmonids.

Fledging success at Caspian tern colonies on the Columbia Plateau varied dramatically. The lowest fledging success observed was at Three Mile Canyon Island, where the colony completely failed due to predation and disturbance by mink. The highest fledging success among the study colonies was at Crescent and Solstice islands in 2001 (Table 2.4). Comparing fledging success to that reported in the Columbia River estuary (Roby et al. 2002), fledging success at these colonies was higher than that at the Rice Island colony and similar to that recorded at East Sand Island (Table 2.4).

Low fledging success at Caspian tern colonies in the Columbia River was attributable to nest predation. At Three Mile Canyon Island, a combination of mink predation on eggs and chicks and the effects of mink disturbance on adult nest attendance caused the failure of the colony. Burness and Morris (1993) documented similar effects of mink on a colony of common terns (*S. hirundo*); although at this site adults did not abandon the colony during nocturnal disturbances, as was seen at Three Mile Canyon Island. Low fledging success at Rice Island in 2000 (Roby et al. 2002; Table 2.4) was associated with extremely high nest predation rates by glaucous-winged/western gulls (*L. glaucescens* x *L. occidentalis*) nesting adjacent to the Rice Island tern colony (D.D. Roby, unpubl. data).

While we rarely observed predation on tern eggs and chicks by gulls at Crescent Island (see Chapter 3), higher rates of gull kleptoparasitism may have limited fledging success at this colony, due to reduced chick provisioning rates and increased energetic demands of adults feeding young. Gull kleptoparasitism rates at Crescent Island were higher than at both colonies in the estuary during 2000 (12.5% at Rice Island, N = 4,340; 0.85% at East Sand Island, N = 4,482; D.D. Roby, unpubl. data). Gulls nest around the perimeter of the Crescent Island colony and thus may have had greater opportunities for kleptoparasitism, as compared to tern colonies in the estuary where gulls nest in separate colonies.

The higher rates of gull kleptoparasitism at Crescent Island compared to Rice Island were surprising considering the high rates of nest predation by gulls at the Rice Island tern colony. This difference in nest predation may be related to differences in size of the gull species present at these two colonies (glaucous-winged/western gulls are larger and more predatory than the California gulls nesting at Crescent Island). In addition, lower levels of disturbance at Crescent Island (see Chapter 3) made opportunistic nest predation by gulls more difficult than at Rice Island, where bald eagle (*Haliaeetus leucocephalus*) activity caused adult terns to frequently flush from their nests (D.D. Roby, unpubl. data).

The high fledging success at the Solstice Island tern colony may be related to lack of nest predation and low gull kleptoparasitism rates. We did not observe opportunistic nest predation by gulls at Solstice Island, although it was much more difficult to observe on-colony behavior at this site because all observations were made from the water. Lower gull kleptoparasitism rates at this site compared to the Crescent Island colony may again be related to fewer gulls nesting in close proximity to tern nests.

We were able to test different methods to estimate colony size at Caspian tern colonies because our study colonies were much smaller than those in the Columbia River estuary (Rice Island in 1999, East Sand Island in 2000 and 2001; Table 2.4). The aerial photo census technique used to estimate colony size during late incubation underestimated the total number of breeding pairs at Crescent Island in 2001, but generated the same estimate as conducting a total count of all incubating birds in 2000. Estimates of the total number of breeding attempts were greater than either of the one-time counts conducted at Crescent Island. The difference between the two types of estimates (staggered vs. one-time) is related to colony synchrony, and thus likely varies depending on the colony and/or year under investigation. We therefore believe the one-time counts are most

comparable among years and colonies, while the staggered counts can be useful in providing estimates of nests initiated at Caspian tern colonies.

Data on the composition of Caspian tern diets demonstrated the dependence on juvenile salmonids as a food source by Caspian terns nesting at Three Mile Canyon and Crescent islands. Caspian terns nesting on Three Mile Canyon Island had a greater proportion of salmonids in the diet than Caspian terns nesting at Crescent Island, and this may be related to differences in foraging habitat in proximity to the colony site. Terns nesting at Crescent Island frequently foraged at nearby ponds, and on the Walla Walla River (see Chapter 4), where they may have had easier access to a wider variety of alternative prey.

While salmonids did not comprise a majority of the diet of Caspian terns nesting at Solstice Island, diet data indicated that terns nesting at this colony were making repeated long-distance trips to the mid-Columbia River where they foraged on juvenile salmonids. While foraging trips in excess of 60 km have been recorded for Caspian terns (Soikkeli 1973, Gill 1976), average foraging distances are typically much smaller. In the Columbia River estuary, for example, radio-tagged Caspian terns foraged on average less than 16 km from the colony site (D.E. Lyons, Oregon State University, unpubl. data).

Compared to the diet of Caspian tern colonies in the Columbia River estuary, Crescent Island terns consumed a greater proportion of salmonids than terns nesting at East Sand Island (46.5% in 2000, 32.5% in 2001), but less than at Rice Island (89.6% in 2000; Roby et al. 2002). Terns nesting at Solstice Island had a lower percentage of salmonids in the diet than terns nesting at either Rice or East Sand island. The lower proportion of salmonids in the diet of terns nesting at East Sand Island compared to Rice Island was likely attributable to greater availability of alternative prey (i.e., marine forage fishes; Roby et al. 2002), which supports the idea that terns nesting at Crescent Island may have had greater access to alternative prey than at Three Mile Canyon Island in 2000 (Table 2.6). It also

suggests that diets of Caspian terns reflect local prey availability, an observation that guided Caspian tern management in the Columbia River estuary (Roby et al. 2002).

The number of active Caspian tern colonies on the Columbia Plateau is likely related to the number of available nesting sites near adequate prey resources. Suitable nest sites for Caspian terns generally have the following features: bare sand habitat, an absence of mammalian predators, and proximity to abundant prey. Social stimulation also seems to be important in colony formation by Caspian terns; on the Columbia Plateau, all tern colonies were associated with larger gull colonies, and in the Columbia River estuary tern decoys and audio playbacks have been used to attract Caspian terns to a restored colony on East Sand Island (Roby et al. 2002). The presence of three small tern colonies on basalt rock islands (Goose Island, Harper Island, and Miller Rocks) was surprising, given that these sites provided little nesting substrate (i.e., sand) for terns to dig nest scrapes. This suggests that suitable nesting sites may be limited within the study area.

While we found islands within the study area with areas of suitable nesting substrate that were not utilized by terns, it is possible that these sites may have either been accessible to mammalian predators, experienced frequent anthropogenic disturbance, or may not have been colonized because of a lack of social stimulation. In Potholes Reservoir, there were many other bare sand islands besides Solstice Island; however, these may not have been colonized because of a lack of sufficient prey in the immediate vicinity. Colonization of new islands in Potholes Reservoir by Caspian terns may have also been affected by the high level of recreational activity within the reservoir (e.g., camping, picnicking, boat traffic) that occurs throughout the Caspian tern breeding season.

The size of Caspian tern colonies within our study area may also be habitat limited. This is supported by the higher nesting densities observed at

Crescent and Three Mile Canyon islands, compared to colonies in the Columbia River estuary. While the size of the Solstice Island tern colony may not have been limited by habitat, as reflected by lower nesting densities, it is likely that the size of this colony was limited by insufficient prey resources in the vicinity of the island. Habitat limitation at Crescent Island (and Three Mile Canyon Island before colony abandonment) may be related to competition with gulls for nest sites. While gulls do not appear to be encroaching upon tern nesting habitat at Crescent Island, their nesting activities may be limiting the expansion of the tern colony. This is supported by the observed increase in nesting density concurrent with an increase in colony size at Crescent Island from 2000 to 2001.

Colony size may also be affected by the availability of habitat elsewhere along the Pacific Coast. Suitable breeding habitat in the Columbia River estuary supports a large number of breeding terns. In the absence of such breeding habitat, terns might disperse to colonies on the Columbia Plateau. However, there was no evidence that displacing terns from the Rice Island colony caused terns to immigrate to colonies further up-river. Given constraints on nesting habitat and prey availability, as well as the impacts of predator activity, it is unlikely that Caspian tern colonies on the Columbia Plateau could experience ecological release, and grow rapidly to a large size, as occurred in the Columbia River estuary (Roby et al. 1998).

The total number of Caspian tern breeding pairs on the Columbia Plateau during the study period remained nearly stable at approximately 1,000 breeding pairs at 4-6 colony sites. If we assume that tern colony area at Crescent Island is fixed due to competition with gulls for nest sites, it is possible that average nest density at Crescent Island could increase to as much as 1.5 pairs/m² (the highest nest density recorded for Caspian terns in the Pacific Northwest; Collis et al. 2002b). This would set an upper size limit at the Crescent Island colony of about 1,000 pairs. If we also assume that (1) the Three Mile Canyon Island is not re-

colonized due to continued mink predation, (2) the Solstice Island colony is limited to a maximum size of 300 pairs due to prey limitation, and (3) the colonies at Goose Island, Harper Island, and Miller Rocks cannot increase due to lack of suitable nesting substrate and/or competition with gulls for breeding habitat, then the size of the Caspian tern sub-population breeding in the Columbia Plateau region is not likely to increase beyond 1,500 pairs. If Three Mile Canyon Island is re-colonized by Caspian terns that nest at densities approaching the highest recorded in the Pacific Northwest (Collis et al. 2002b), the upper limit to the size of the sub-population would be as much as 2,000 pairs. This upper estimate would represent only 22% of the number of Caspian tern pairs breeding in the Columbia River estuary during the study period (Table 2.4) and approximately 14% of the Pacific Coast population (Wires and Cuthbert 2000, Shuford and Craig 2002). While the majority of Caspian terns nesting at colonies on the Columbia Plateau rely on juvenile salmonids as a food source, the apparent stability of this sub-population and its relatively low numbers will likely keep the level of predation on juvenile salmonids well below that currently observed in the Columbia River estuary.

The findings of this study suggest that (1) while Caspian tern colonies are highly dynamic within the study area, there is no evidence that management of Caspian terns in the Columbia River estuary has caused emigration of terns to colonies on the mid-Columbia River, (2) the number and size of Caspian tern colonies on the Columbia Plateau are likely constrained by the availability of suitable nesting habitat near abundant prey, and (3) while Caspian terns nesting at colonies on the mid-Columbia River rely more on juvenile salmonids as a food source than terns nesting at East Sand Island in the Columbia River estuary, the stability and small size of the Columbia Plateau sub-population will likely keep the magnitude of tern predation on juvenile salmonids in this region well below that currently observed in the Columbia River estuary.

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Chapter 3

EFFECTS OF NEST DENSITY, LOCATION, AND TIMING
ON BREEDING SUCCESS OF CASPIAN TERNS

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ABSTRACT

A major hypothesis for the evolution of coloniality in birds is the protection afforded against avian predators. The benefits of a high degree of coloniality may be counter-balanced by the negative effects of high levels of intraspecific aggression on breeding success. We investigated the effects of nest density, nest location within the colony, and timing of nest initiation on productivity of Caspian terns (*Sterna caspia*) on Crescent Island in the mid-Columbia River, Washington, USA. We hypothesized that nest density would be negatively associated with productivity, given low levels of avian nest predation at this colony. We used a rangefinder to obtain spatial data on Caspian tern nests, and used these data to calculate nest characteristics (nest density, nearest neighbor distance, and distance to colony edge) for a randomly-selected subset of nests monitored for productivity and timing of nest initiation. The Crescent Island tern colony consisted of 688 breeding pairs and the range of nesting densities was 0.25-1.48 nests/m². Productivity did not differ between nests in high- and low-density areas of the colony, and was strongly negatively related to nest initiation date. Early nests were more productive, were located in areas of higher nest density, and were further from the colony edge than late nests; the breeders at these nests may have been older and more experienced. Conversely, the strong effect of timing may have been attributable to seasonal declines in prey resources for terns. Our results suggest that Caspian terns nesting at the highest densities observed in this study do not incur immediate reproductive costs, despite the increased potential for encounters with aggressive conspecifics.

INTRODUCTION

The evolution and adaptive significance of coloniality in birds is a topic that has received considerable attention and study in the past several decades (see reviews by Wittenberger and Hunt 1985, Siegel-Causey and Kharitonov 1990, Danchin and Wagner 1997). One of the major hypotheses developed to explain coloniality in birds is the notion that coloniality affords protection against predators, particularly avian predators (Kruuk 1964, Patterson 1965, Götmark and Andersson 1984, Anderson and Hodum 1993). However, studies investigating the effects of one aspect of coloniality, nest density, on breeding success have produced mixed results. Birkhead (1977) found significant positive correlations between nesting density and breeding success in common murrets (*Uria aalge*), while Butler and Trivelpiece (1981) found that fledging success was significantly lower in high-density nesting areas for great black-backed gulls (*Larus marinus*). In the common tern (*Sterna hirundo*), Becker (1995) found breeding success was positively correlated with nesting density and negatively correlated with nearest neighbor distance, while Houde (1983) found no relationship between density and survival of chicks after accounting for habitat type. Breeding success was highest for intermediate densities in herring gulls (*L. argentatus*, Parsons 1976), but was not related to nest density in ring-billed gulls (*L. delawarensis*, Dexheimer and Southern 1974).

Hunt and Hunt (1976) suggested that with coloniality comes conflicting needs for protection against nest predation and the avoidance of intraspecific aggression, which may explain some of the variation described above. Because these factors are likely to influence the reproductive success of colonial birds in opposing ways, it may be useful to examine cases where only one of these considerations is relevant (i.e., in colonial species where intraspecific aggression is minimal or in colonies with virtually no nest predation). In this study, we

examined the relationship between nesting density and breeding success at a colony where nest predation rarely occurred. In the absence of avian nest predation, it is expected that a high degree of coloniality will negatively affect breeding success if interference by conspecifics is an important source of mortality for eggs and young (Hunt and Hunt 1976).

Caspian terns (*Sterna caspia*) are facultatively colonial waterbirds that typically nest in association with gulls and other terns (Cuthbert and Wires 1999). Gulls can opportunistically prey on tern eggs and chicks, especially after disturbance events (Penland 1981, Roby et al. 1998). This study was conducted at a Caspian tern colony on Crescent Island in the mid-Columbia River, Washington, USA. We hypothesized that nest density would be negatively correlated with productivity at Crescent Island, because Caspian terns at this site experience low levels of disturbance (Figure 3.1; see Methods), and nest predation by gulls rarely occurs (see Results). The low disturbance rates also reflect the low frequency of visits by other avian predators that can flush adult Caspian terns at the colony, such as bald eagles (*Haliaeetus leucocephalus*; Collis et al. 1999). Intraspecific aggression, on the other hand, may be an important source of mortality for Caspian tern chicks, which are semi-nidifugous and can be attacked and/or killed by neighboring adults (Bent 1921, Cuthbert and Wires 1999).

Because there are likely a number of other factors that influence the relationship between coloniality and breeding success, we also collected data on nest centrality and breeding chronology to examine their effects in our analysis of Caspian tern reproductive success. Centrality may be either positively (Coulson 1968, Becker 1995) or negatively (Brunton 1997) correlated with productivity, and this relationship may be affected by the type of nest predator present (Brunton 1997). Breeding chronology can also be an important factor, and it has been

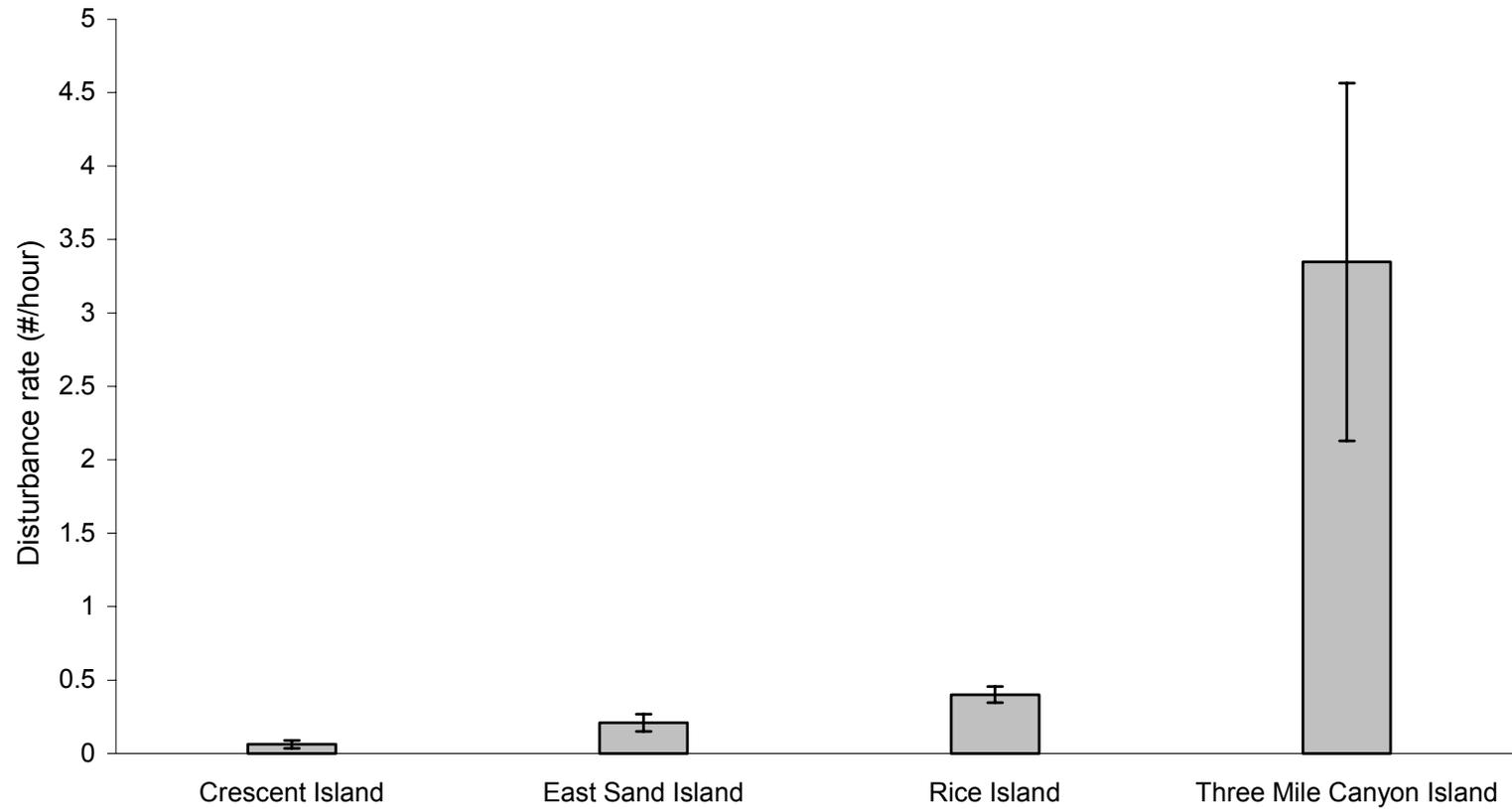


Figure 3.1. Mean disturbance rates (number of disturbances observed per hour of observation \pm SE) for Caspian tern colonies in the Columbia River during the 2000 breeding season. There were significant differences among all groups ($\chi^2_3 = 70.8821$, $P < 0.0001$), and between Crescent Island and East Sand Island ($Z = -3.7057$, $P = 0.0002$).

generally found that early (Davis and Dunn 1976, Becker 1995, Massoni and Reboreda 2001) or peak (Patterson 1965, Parsons 1975) breeders are more successful in raising a brood, although this relationship does not always hold (Birkhead 1977, Hunt and Hunt 1975). In addition, because distance to nearest neighbors may significantly affect breeding success (Becker 1995) and aggression rates of conspecifics (Hill et al. 1997), we included this factor in our analysis to determine if its effect differed from our primary measure of coloniality, nest density. Thus this study assessed the effect of coloniality on avian reproductive success in the near absence of nest predation, after accounting for position within the colony and timing of breeding.

METHODS

STUDY AREA

This study was conducted during April-July 2001 on Crescent Island (46.094°N, 118.929°W) in the reservoir created by McNary Dam on the Columbia River, Washington, USA. Crescent Island was created from dredge-spoil in 1985 as waterfowl nesting habitat, and soon afterwards was colonized by Caspian terns (Ackerman 1994). In 2001, an estimated 688 pairs of Caspian terns nested in a single colony on the northeastern side of the island. The area of Crescent Island is 3.2 ha, and the area of the Caspian tern colony measured 676 m² (0.07 ha) in 2001. Overall nesting density in 2001 was 1.02 nests/m², and fledging success was 1.02 fledglings/breeding pair (see Chapter 2 for details). A large colony of California gulls (*L. californicus*) was established on Crescent Island shortly after the Caspian tern colony formed (Ackerman 1994), and consisted of approximately 2,700 breeding pairs in 2001 (M. Antolos, unpubl. data); small numbers of ring-billed gulls also nested on the island. California

gulls nested around the perimeter of the Caspian tern colony, and there was some overlap at the boundary between the two colonies.

DISTURBANCE RATES

Data on disturbance rates were collected in 2000 and 2001 by dividing the number of disturbances recorded in a day by the number of observation hours for that day, and then averaging these rates across the season. A disturbance was defined as an episode where Caspian terns flushed from their nests, creating the potential for nest predation by opportunistic gulls. Three Caspian tern colonies located in the lower Columbia River were used for comparison to assess the relative level of disturbance at Crescent Island in 2000 and to help test hypotheses developed for the present study. These three tern colonies on East Sand Island, Rice Island, and Three Mile Canyon Island were also under study by the authors during the 2000 breeding season. Average disturbance rate was also calculated at Crescent Island in 2001, to assess the conditions under which the study took place. Disturbance rates were used instead of predation rates in this comparison because it was often difficult to determine if a predation event occurred during a disturbance, especially at large colonies. In order to validate the assumption that disturbance rates reflect predation intensity at Caspian tern colonies, additional observations of nest predation events are reported in this analysis.

NEST MONITORING

Productivity plots were delineated by placing a large grid on the Caspian tern colony before the initiation of egg laying, so that most of the colony was within the grid. The grid consisted of 5 m x 5 m plots that were created by placing brightly painted wooden stakes at each corner and connecting them with high-visibility nylon cord. The cord was then marked at one-meter intervals with brightly colored tags. These landmarks provided references so that each initiated

Caspian tern nest (whether it fell inside or outside a plot) could be mapped from an observation blind approximately 16 m from the edge of the tern colony. Nests were randomly selected for monitoring as they were initiated until early in the hatching period, so that monitored nests encompassed most of the range of breeding times at this asynchronous colony. These selected nests were then monitored from the blind a minimum of every 3 days throughout the course of the breeding season, so that productivity and chronology could be determined for each nest. Productivity of a nest was defined as the number of surviving chicks at 20 days post-hatch, and the chronology of a nest was measured as the date on which the first chick hatched. Caspian tern chicks do not fledge until they are approximately 37 days old (Cuthbert and Wires 1999); however, it was not possible to continue monitoring survival of young from a particular nest after about 20 days post-hatch, due to increased movements by the chicks and the deterioration of the nest scrape. We assumed that our measure of nest success, although not a final assessment of fledging success, succeeded in capturing the variation in productivity among nests.

Hatch date was determined by observing monitored nests for the presence of chicks; when nests were not checked on successive days, the midpoint of the dates when the colony was visited was recorded as the hatch date, following Mayfield (1975). Hatch date was easier to determine from the blind than lay date because of the change in posture and behavior of adults at hatch, whereas early in the nesting season it was difficult to determine whether an adult was sitting on an empty scrape or on an egg.

NEST SITE CHARACTERISTICS

Spatial data were obtained on all existing Caspian tern nests early in the hatching period (15-17 May) using a total station (Leica TCRA 1105) with an integrated reflectorless electronic distance meter accurate to ± 5 mm. Slope

distance, horizontal angle, and vertical angle measurements for individual Caspian tern nests were recorded and later downloaded from the total station, then converted to (x,y) coordinates using general trigonometric formulae. Coordinates were used to calculate nearest neighbor distance (m), distance to colony edge (m), and density of nests within a 5-m diameter circle (nests/m²) for each monitored nest. The colony edge was determined by importing nest coordinates into ArcView® software (Environmental Systems Research Institute, Inc.), and defining a polygon connecting the outermost Caspian tern nests, so that the segment length did not exceed 3.5 m. Those nests situated on this polygon were defined as “edge point nests.” This short segment length allowed the polygon to follow the contours of the colony at a fine scale, so that “edge point nests” could be used as a reference for calculating distance to colony edge. Coordinate data were then used to generate distances from each monitored nest to every other nest on the colony. From these data, the minimum distance between a monitored nest and any other nest was defined as the distance to its nearest neighbor, and the minimum distance to an “edge point nest” was defined as the distance to colony edge.

The number of nests with distances less than or equal to 2.5 m were summed and used to calculate nest density within a 5-m diameter circle of each monitored nest. Preliminary analysis demonstrated that when using a smaller, 1-m diameter circle, densities had very little variability, while the variation in densities was similar using either a 5-m or 10-m diameter circle. Because we believed that a 5-m diameter circle would be more representative of the local environment for an individual nest, we chose this circle size.

Because all spatial data had to be collected by 17 May for logistical reasons, we were not able to include all nests initiated at the Crescent Island colony in our analysis. Between 12 and 44 more nests were initiated at this colony after spatial data collection was completed (see Chapter 2). Given our

large sample size of monitored nests ($N = 218$ nests) and the small percentage of the total nests in the colony initiated after 17 May (between 1.7% and 6.5%), we do not think that the omission of these later nests had an appreciable effect on the results of this study.

GROUPING OF VARIABLES

In order to assess effects of each independent variable on the response variable of productivity, and to examine relationships among independent variables, data were broken up into discrete intervals, and comparisons among groups were made. Nests were distinguished by density as either falling into LOW (< 1.0 nests/m²) or HIGH (≥ 1.0 nests/m²) density groups. This roughly bisected the range of densities and the number of data points. Nests were also grouped by nearest neighbor distance as either nests with NEAR (< 0.6 m) or FAR (≥ 0.6 m) neighbors. Preliminary analysis indicated that nests with neighbors closer than 0.6 m may have been affected differently by their neighbors than nests with more distant nearest neighbors. Distance to edge was used to group nests as either EDGE or CENTER nests. EDGE nests were defined as those < 2.5 m from the colony edge and all others as CENTER nests. We chose 2.5 m because this distance roughly equals an average of three nests in from the colony edge, a characteristic used to define edge nests in a least tern (*S. antillarum*) colony (Brunton 1997). Timing of nest initiation was either broken up into one-week intervals, or grouped as EARLY or LATE nests. EARLY nests were defined as those with hatch dates that fell within the first three weeks of hatching (11-31 May) and LATE nests as those hatching after this period (1 Jun-6 Jul; nearly all LATE nests hatched chicks in the 3-week period after 31 May, with the exception of one very late nest).

All observations in this study were made from a blind in order to minimize researcher disturbance and the potential for nest failure. By mapping and

monitoring nests from a blind and using a rangefinder to determine nest site characteristics, we were able to obtain the entire data set without setting foot on the colony, a necessary requirement for the conditions under which we wished to test our hypothesis (in a relatively undisturbed colony where nest predation rarely occurred).

STATISTICAL ANALYSIS

Nonparametric Kruskal-Wallis and Wilcoxon rank-sum tests were used to test for group differences among disturbance rates and to assess relationships among variables (productivity, nest density, nearest neighbor distance, distance to colony edge, and hatch date).

In order to assess the relative effects of all variables, data were then analyzed using Poisson log-linear regression for counts. Poisson regression was used because of the discrete nature of the response (number of chicks raised). Although the variables measured in this study were related, correlations among variables did not exceed 0.5, so we proceeded with all variables included in the regression analysis. A model including only the main effects of nest density, nearest neighbor distance, distance to colony edge, and hatch date was compared to a fuller model that included interaction, quadratic, and cubic terms to assess the goodness-of-fit of the inferential model using a drop-in-deviance test. Because the fuller model did not significantly improve the fit to the data ($\chi^2_{12} = 5.85139$, $P = 0.92$), the main effects model was used as the inferential model for the rest of the analysis. Drop-in-deviance tests were then used to assess the significance of each main effect included in this analysis. All reported P -values are two-sided.

RESULTS

DISTURBANCE RATES

Average disturbance rates differed among the four Columbia River Caspian tern colonies during the 2000 breeding season (Kruskal-Wallis test, $\chi^2_3 = 70.8821$, $P < 0.0001$), and Crescent Island had the lowest average rate of disturbance (Figure 3.1). The average disturbance rate at Crescent Island in 2000 was significantly lower than that observed at East Sand Island, the colony with the next lowest average disturbance rate (Wilcoxon rank-sum test, $Z = -3.7057$, $P = 0.0002$). In 2001, the average disturbance rate at Crescent Island did not differ from that observed on Crescent Island in 2000 ($Z = 1.082$, $P = 0.28$), and was still significantly lower than that observed at East Sand Island in 2000 ($Z = -2.8229$, $P = 0.0048$).

On Crescent Island in 2001, only one nest predation event was witnessed in over 250 hours of observation: a California gull was seen opportunistically preying on a single tern egg during a disturbance event. At Rice Island in 2000, where disturbance rates were higher, 129 separate nest predation events were witnessed during approximately 470 observation hours. It is difficult to compare numbers of nest predation events between Crescent Island and Three Mile Canyon Island or East Sand Island because (1) high disturbance rates at Three Mile Canyon Island were related to nocturnal predation events by mink (*Mustela vison*; see Chapter 2), and thus predation events were not witnessed directly; and (2) active gull control at East Sand Island in 2000 kept nest predation levels artificially low despite higher disturbance rates than at Crescent Island.

SUMMARY STATISTICS

Mean number of chicks at the nest at 20 days post-hatch was 1.48 chicks/nest and ranged from 0 to 3 chicks/nest (Table 3.1). Because considerable

Table 3.1. Summary of characteristics of Caspian tern nests (N = 218) monitored on Crescent Island in 2001.

	Mean \pm SE	Range
Productivity (chicks/nest)	1.48 \pm 0.046	0 – 3
Nest density (nests/m ²)	0.96 \pm 0.014	0.25 – 1.48
Nearest neighbor distance (m)	0.76 \pm 0.010	0.35 – 1.50
Distance to colony edge (m)	3.65 \pm 0.190	0 – 11.0
Hatch date (Julian days)	146.8 \pm 0.531	131 – 187

mortality occurred to Caspian tern chicks between 20 days of age and fledging, this measure of productivity was higher than overall fledging success at Crescent Island in 2001 (1.02 fledglings/pair; Chapter 2). Variation was similar for both measures of coloniality: nest density and nearest neighbor distance (Table 3.1). Distance to colony edge ranged from 0 to 11.0 m, and hatch dates spanned a period of over 6 weeks, demonstrating the marked nesting asynchrony at this colony.

COLONIALITY

Productivity of Caspian tern nests did not differ between LOW and HIGH density groups ($Z = -1.3463$, $P = 0.18$; Figure 3.2a), contrary to our hypothesis. Productivity was, however, lower among nests with NEAR neighbors than those with FAR neighbors ($Z = -7.6839$, $P < 0.0001$; Figure 3.2b). Nest density and nearest neighbor distance were negatively related, with larger nearest neighbor distances in the LOW density group than in the HIGH density group ($Z = 2.0656$, $P = 0.039$).

CENTRALITY

CENTER nests were more productive than EDGE nests at this colony ($Z = 3.2768$, $P = 0.001$; Figure 3.2c). EDGE nests also had lower average densities than CENTER nests ($Z = -7.4404$, $P < 0.0001$; Figure 3.3a), but average nearest neighbor distance did not differ between EDGE and CENTER nests ($Z = 0.5818$, $P = 0.56$; Figure 3.3b). The relationship between distance to colony edge and hatch date illustrated the pattern of nest initiation on the colony at Crescent Island. LATE nests were significantly closer to the edge than EARLY nests ($Z = 5.9316$, $P < 0.0001$). However, when distance to colony edge was grouped by one-week intervals, it was evident that the very earliest nests were not those furthest from the colony edge (Figure 3.4). This is because the earliest nests were initiated on

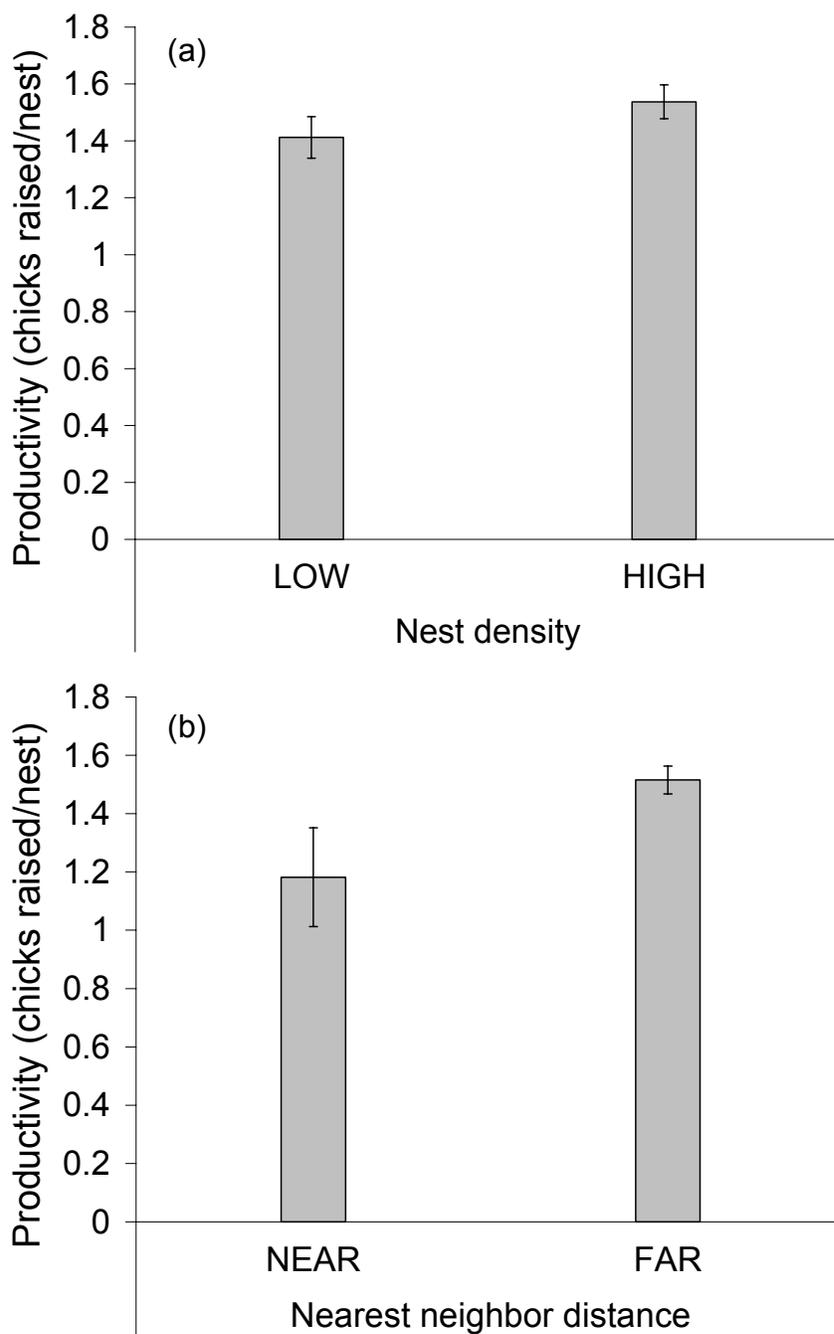


Figure 3.2. Mean productivity (\pm SE) of Caspian tern nests at the Crescent Island colony in LOW ($N = 97$) and HIGH ($N = 121$) density regions (a), for nests with NEAR ($N = 22$) and FAR ($N = 196$) neighbors (b), and for nests situated at the EDGE ($N = 96$) and the CENTER ($N = 122$) of the colony (c).

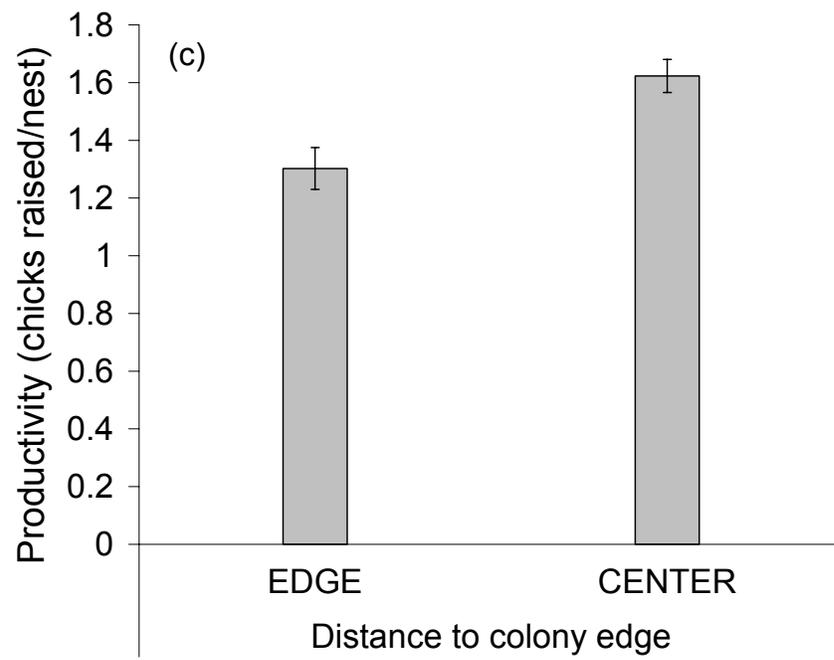


Figure 3.2. (Continued)

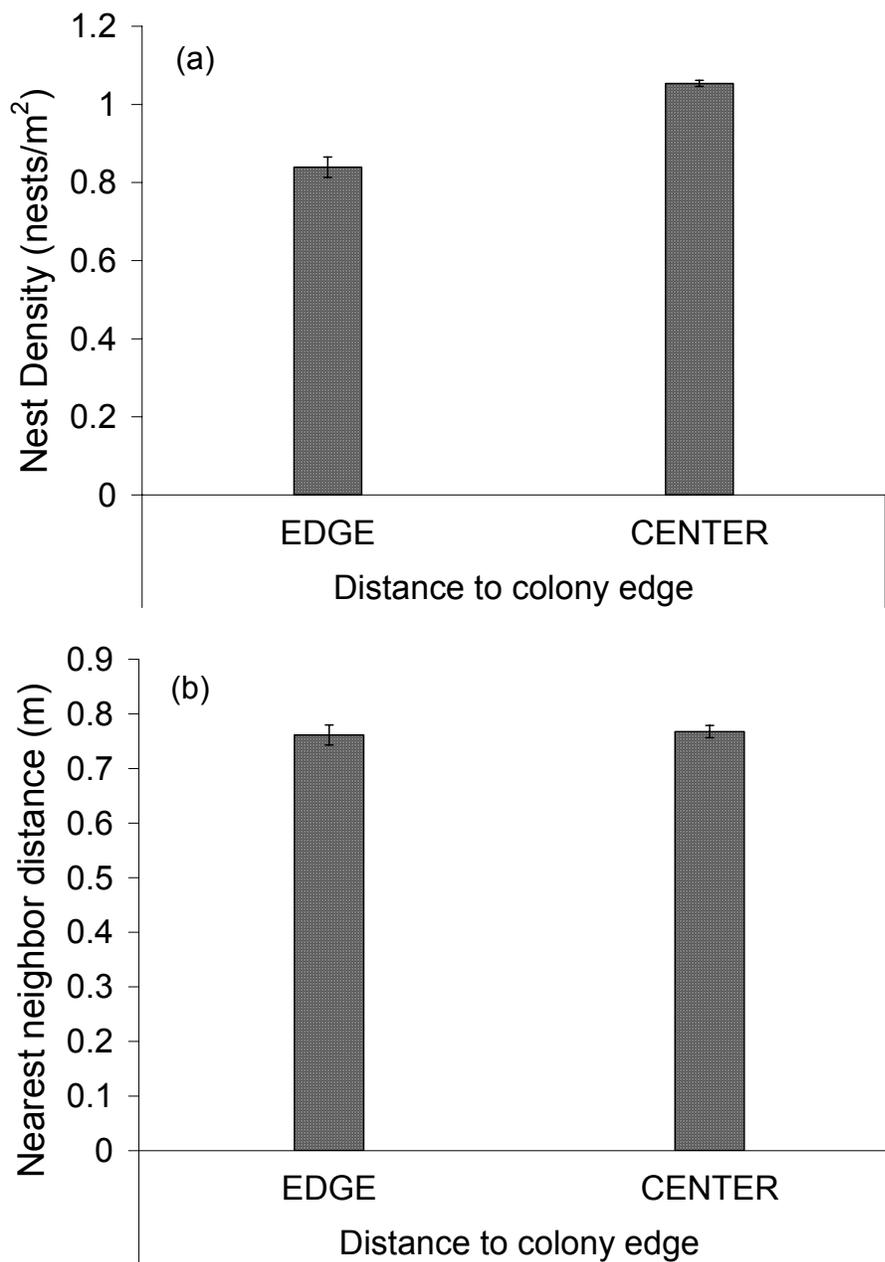


Figure 3.3. Mean nest density (a) and nearest neighbor distance (b) \pm SE for EDGE (N = 96) and CENTER (N = 122) nests at the Caspian tern colony on Crescent Island in 2001.

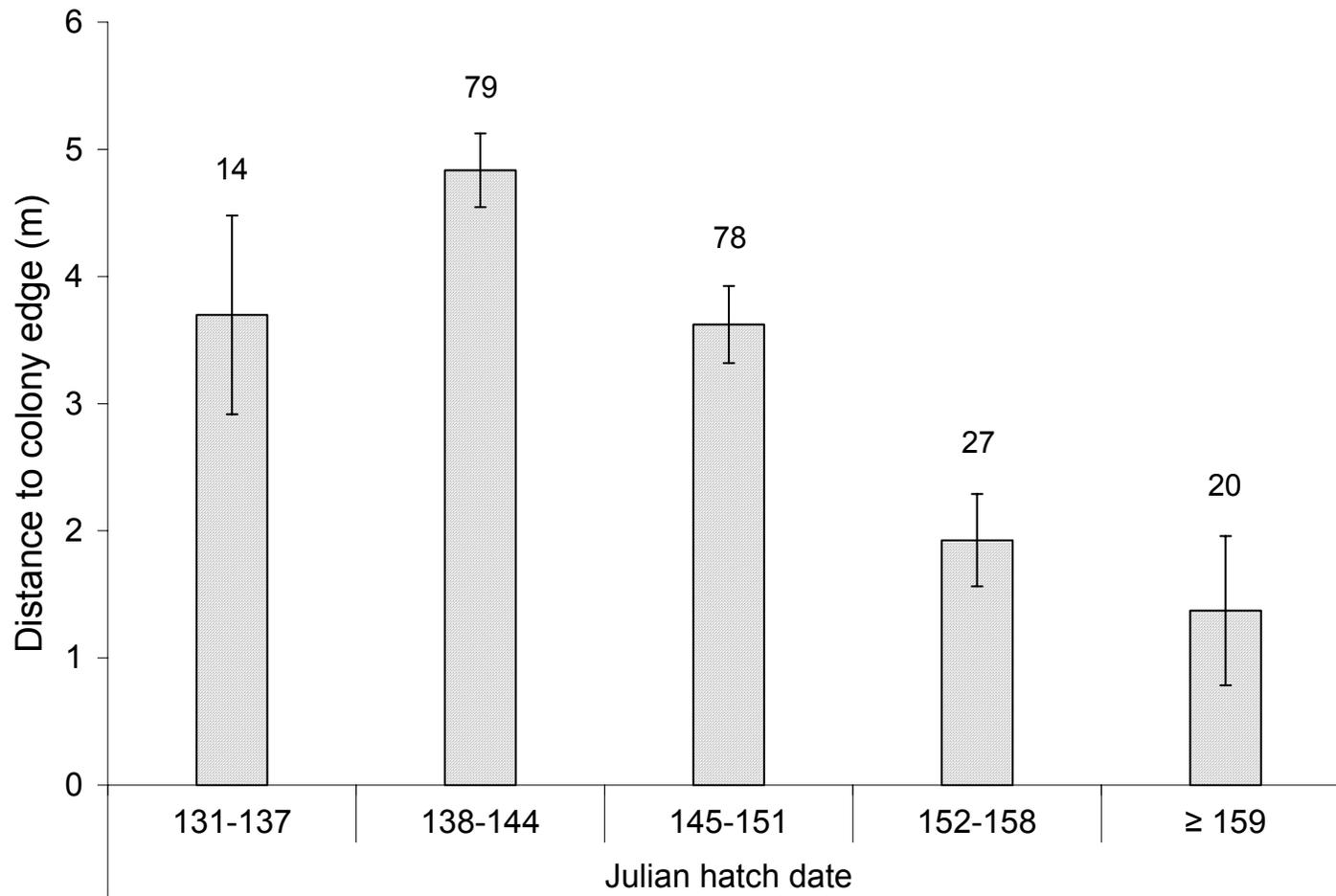


Figure 3.4. Mean distance to colony edge (\pm SE) for Caspian tern nests at the Crescent Island colony grouped by Julian hatch date. Distance to edge differed significantly among groups ($\chi^2_4 = 45.6486$, $P < 0.0001$).

the edge of the colony bordering the shoreline of Crescent Island. While this first group of nests was at the colony's edge, the majority of EARLY nests were in the area of the colony that eventually became the center (as LATE nests filled in around the edges of the colony). Figure 3.5 presents the pattern of nest initiation by approximate laying date.

TIMING

There was a strong negative relationship between productivity and hatch date. EARLY nests were more productive than LATE nests ($Z = 7.0665$, $P < 0.0001$), and the negative trend was evident between each successive one-week interval (Figure 3.6). EARLY nests also had higher nest densities than LATE nests ($Z = 5.0901$, $P < 0.0001$; Figure 3.7a), but there was no difference in nearest neighbor distance between EARLY and LATE nests ($Z = 1.1019$, $P = 0.27$; Figure 3.7b).

POISSON REGRESSION

Nest density was not significantly associated with productivity after accounting for the main effects of nearest neighbor distance, distance to colony edge, and hatch date ($\chi^2_1 = 0.00494$, $P = 0.94$, from a drop-in-deviance test). Similarly, nearest neighbor distance ($\chi^2_1 = 0.3281$, $P = 0.57$) and distance to colony edge ($\chi^2_1 = 0.02646$, $P = 0.87$) did not significantly affect productivity, after accounting for the other variables in our inferential model. Hatch date, on the other hand, was a highly significant factor, even after accounting for all other variables ($\chi^2_1 = 18.38139$, $P < 0.0001$). Estimates and standard errors of each coefficient in this regression analysis are presented in Table 3.2. Total variation in productivity explained by this inferential model was low ($R^2 = 22.8\%$), so there were likely other factors affecting productivity besides those included in this analysis. These may have included, but are not limited to: age and breeding

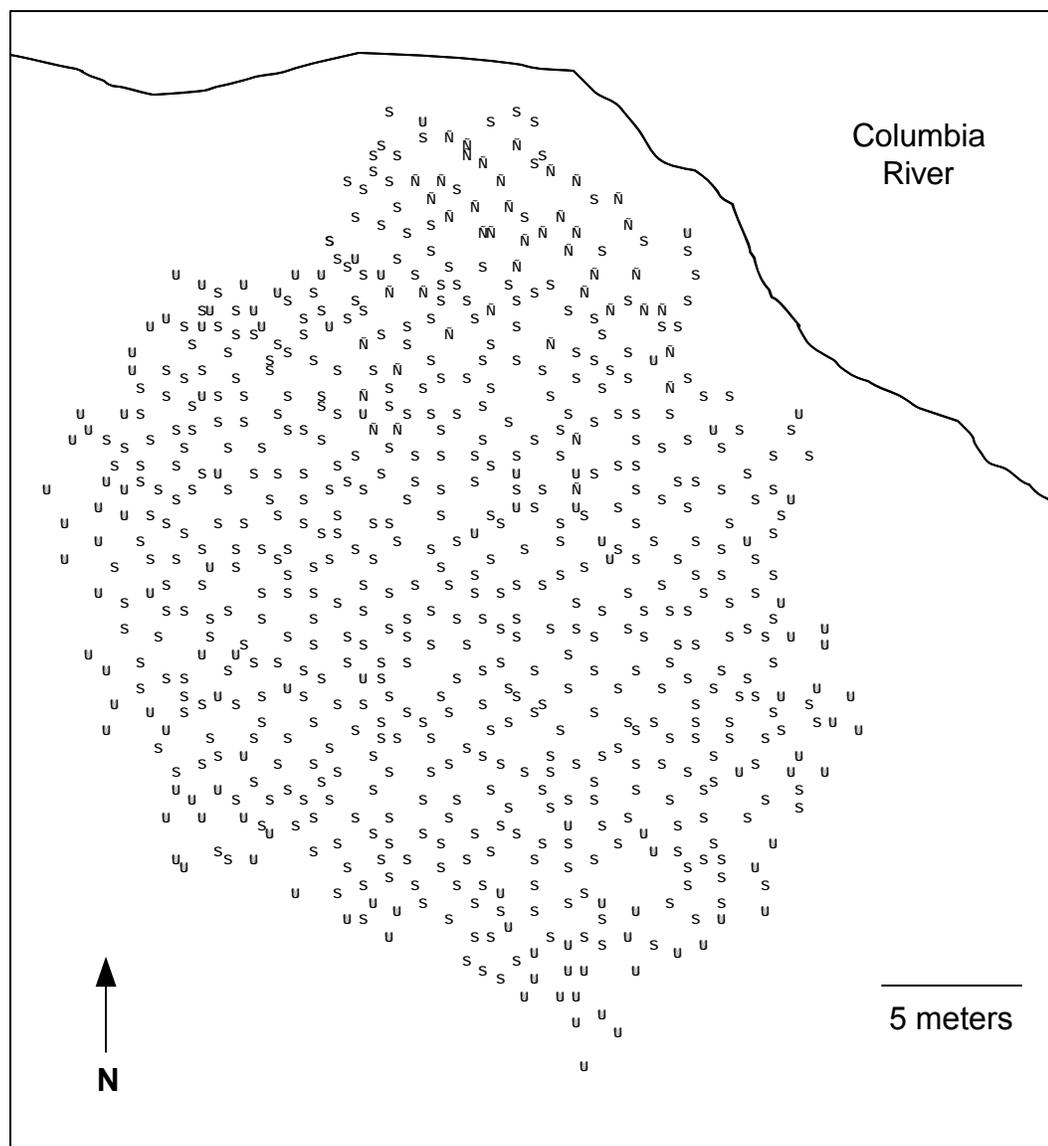


Figure 3.5. Coded map of Caspian tern nests on Crescent Island, 2001. Symbols indicate approximate initiation date separated by the first week of egg-laying (16-22 Apr [+]), the middle two weeks of egg-laying (23 Apr-6 May [○]), and the last week and a half of egg-laying (7-17 May [■]) for which we were able to collect spatial data.

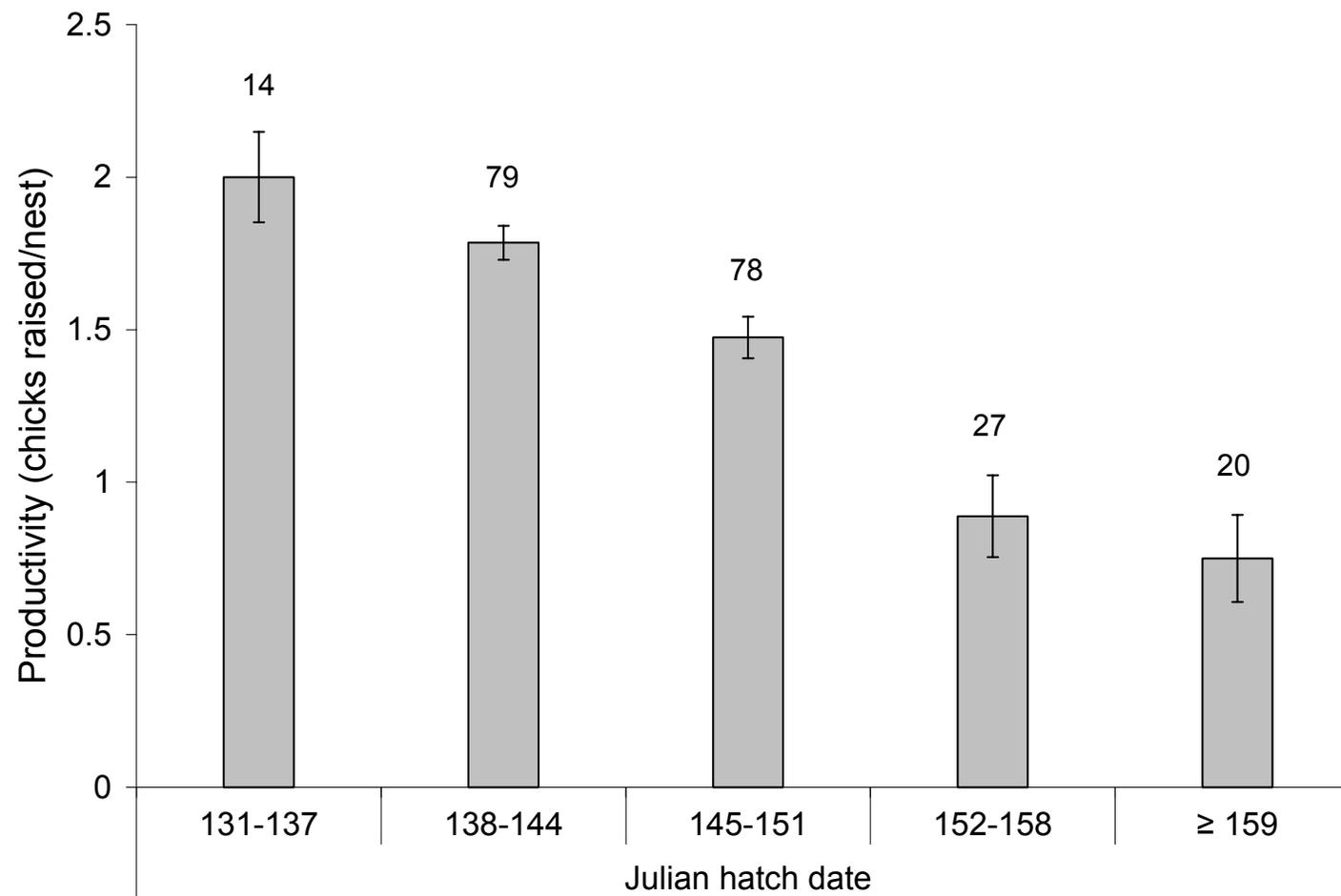


Figure 3.6. Mean productivity (\pm SE) for Caspian tern nests at the Crescent Island colony grouped by Julian hatch date. Productivity differed significantly among groups ($\chi^2_4 = 63.0984$, $P < 0.0001$).

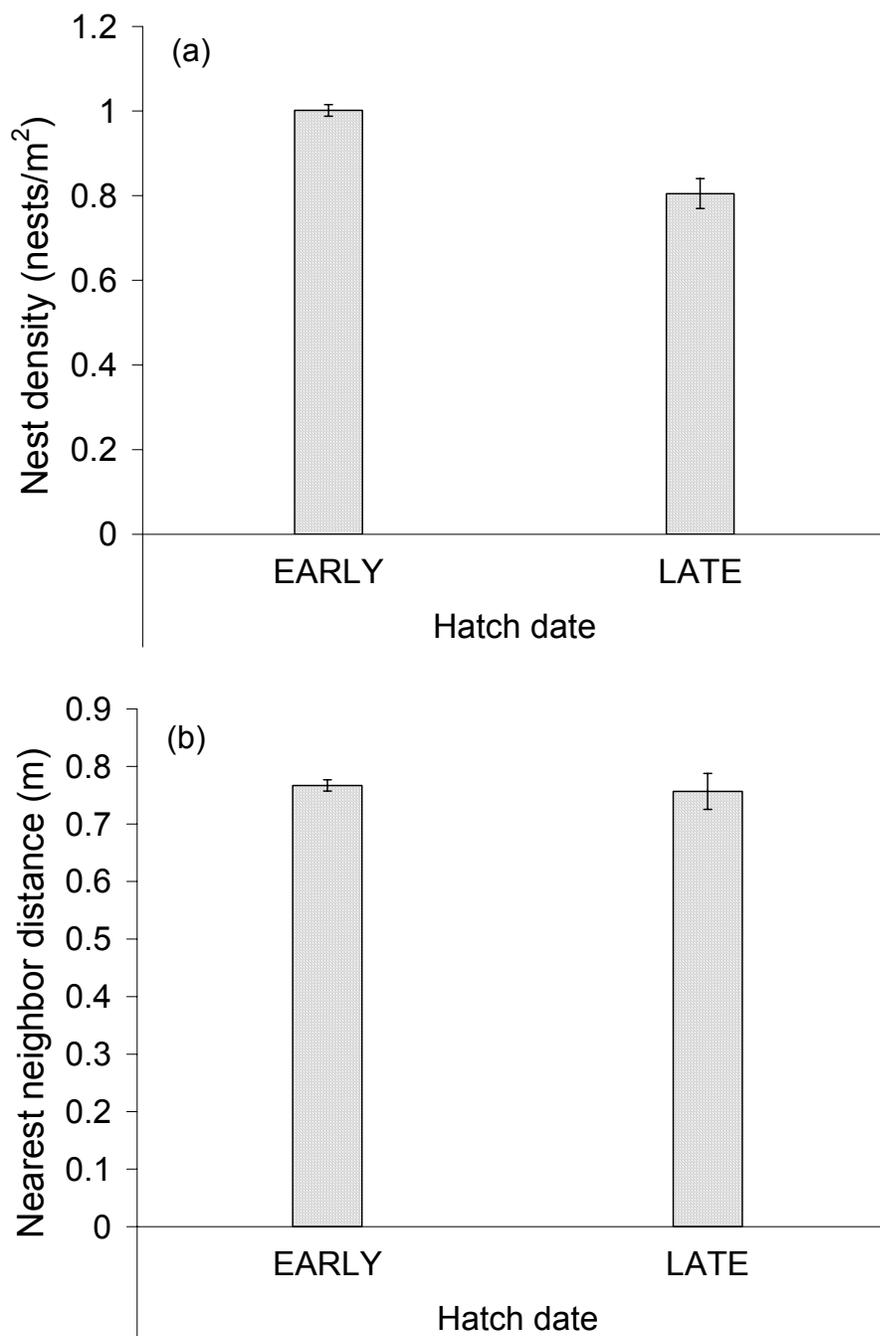


Figure 3.7. Mean nest density (a) and nearest neighbor distance (b) \pm SE for EARLY (N = 171) and LATE (N = 47) nests at the Crescent Island Caspian tern colony in 2001.

Table 3.2. Poisson regression output for a model of the main effects of nest density, nearest neighbor distance, distance to colony edge, and hatch date on productivity of Caspian tern nests at Crescent Island in 2001. *P*-values are approximate two-sided values derived from Wald's tests for single coefficients.

Coefficients	Estimate	SE	Z-statistic	<i>P</i> -value
(Intercept)	5.738	1.479	3.879	0.0001
Nest density	-0.024	0.341	-0.070	0.94
Nearest neighbor distance	0.228	0.397	0.575	0.57
Distance to colony edge	-0.004	0.024	-0.163	0.87
Hatch date	-0.038	0.009	-4.176	< 0.0001

experience of adults; variation among adults in foraging proficiency (which may affect provisioning rates and/or quality of food provisioned to chicks); variation among adults in avoiding kleptoparasitism of prey items by gulls (see Chapter 2); and individual differences in aggressiveness of conspecifics not accounted for in variables measured.

DISCUSSION

The study of coloniality can be greatly enhanced by the use of reflectorless, high-accuracy surveying equipment, such as the total station used in this study to remotely measure nest position and distances among nests. The data that this type of equipment can generate, combined with observations from a blind, eliminates the need for disruptive on-colony work, which can confound the interpretation of results. We therefore recommend this methodology for studies where nest contents can be observed remotely, and where researcher disturbance might otherwise cause mortality and/or stress to colonially breeding birds.

Low disturbance rates at Crescent Island, and the observation of only one tern egg lost to nest predators during the course of this study, support our assumption that nest predation is not an important source of egg or chick mortality at the Crescent Island colony (other sources of chick mortality are discussed below). Contrary to our prediction, however, productivity of Caspian terns at Crescent Island was not negatively associated with nest density. This was the case whether productivity was compared between LOW and HIGH density groups, or the relative effect of density was assessed in our regression analysis. Nests with NEAR neighbors were, however, less productive than other nests, but this relationship did not hold when all variables were considered in our regression model. This suggests that intraspecific aggression did not cause significant mortality to chicks at Crescent Island, assuming that nest density and nearest

neighbor distance approximate the level of aggression experienced by chicks across the colony.

While EDGE nests were less productive than CENTER nests, distance to colony edge was not a significant factor influencing productivity in our regression analysis. This is likely due to the generally later nest initiation of EDGE nests, coupled with the strong negative relationship between productivity and nest initiation date. This suggests that analyses of edge effects on reproductive success of colonially nesting birds should account for nest initiation date in order to verify that position of the nest in the colony is the primary factor influencing nest success. EDGE nests also had lower densities than CENTER nests, but did not differ in terms of nearest neighbor distance. This indicates that nest density and nearest neighbor distance are not equivalent factors and both should be included in an assessment of coloniality, because their effects on breeding success may differ depending on location within the colony.

The relationship between timing of nest initiation and distance to the colony edge (Figure 3.4) and the presence of edge effects on productivity (when analyzed singularly; Figure 3.2c) support the central-periphery model of nest distribution (Coulson 1968, see Velando and Freire 2001). That is, in general, birds breeding in the center of a colony initiate nests earlier, and are thus more successful than those at the edge. The pattern of nest initiation at Crescent Island differed slightly from this general model, however, in that a portion of the Caspian tern colony bordered the Columbia River, and the earliest breeders selected this area over what eventually became the center of the colony (Figure 3.5). Nest initiation started at the water's edge and expanded outward, with later nests filling in around the edges of the colony. This suggests that patterns of nest initiation may be colony-specific and depend on local features. There was also some evidence that very late breeders initiated nests close to earlier, established nests (Figure 3.5). This finding is consistent with the "central-satellite"

distribution model proposed by Velando and Freire (2001). In this model, poorer-quality individuals initiate nests near a central, high-quality pair. Although this pattern only occurred in a small number of nests, these late breeders may be attempting to gain extra-pair fertilizations (Wagner et al. 1996), “commodities” (Danchin and Wagner 1997), or opportunities to acquire better sites and/or mates for the next breeding season (Aebischer et al. 1995, Velando and Freire 2001).

The strong negative relationship between hatch date and productivity, both when analyzed individually and when included with all variables in our regression analysis, demonstrates the importance of timing in determining breeding success of Caspian terns at this colony. Early nests were more productive, were in areas of higher nest density, and were generally further from the colony edge than late nests. The relationship between nest initiation date and productivity may be related to quality of adults, seasonal changes in food availability, or a combination of both. It has been demonstrated that early nesting birds are often older, more experienced individuals (e.g., Coulson and White 1958), and that seasonal declines in reproductive parameters, such as fledging success (Verhulst et al. 1995), and clutch size (Christians et al. 2001), may be attributable to quality of individuals alone. Within-cohort analyses (Perrins 1970) and food supplementation experimentation (Brinkhof and Cavé 1997, Siikamäki 1998) have also provided evidence that declining food resources may provide the basis for seasonal declines in productivity.

The results of this study support the hypothesis that the major source of chick mortality at Crescent Island was undernourishment. The following observations support this hypothesis: (1) predation on tern chicks was never witnessed during the 2001 breeding season, (2) there was no evidence of weather-related chick mortality, and (3) our analysis suggests that intraspecific aggression did not cause chick mortality, despite anecdotal evidence that chicks frequently

experienced aggressive attacks by conspecific adults. In addition, this hypothesis is supported by body mass data indicating that chicks at Crescent Island fledged at lower average mass than chicks at other Caspian tern colonies in the Columbia River (D.D. Roby, unpubl. data). There was evidence that Crescent Island chicks may have had a high incidence of ulcerative pododermatitis, a bacterial infection commonly known as bumblefoot, compared to chicks from other Columbia River colonies, but it is not clear whether this disease caused chick mortality or morbidity.

Assuming that undernourishment was the main cause of chick mortality at Crescent Island, it would be difficult to infer whether seasonal declines in productivity were due to a decline in prey resources *per se* or to inefficient provisioning by younger, less experienced adults. An analysis of Caspian tern diet at Crescent Island demonstrated that during this study juvenile salmonids (*Oncorhynchus* spp.) comprised the majority of the diet (68%), and that the proportion of salmonids in the diet declined as the chick-rearing period progressed (see Chapter 2). The decrease in salmonids in the diet of Crescent Island terns coincided with declines in the number of juvenile salmonids migrating through the mid-Columbia River late in the breeding season (FPC 2003). This decline may signal a sharp drop in forage fish availability late in the nestling period, when chick food demand is greatest. While declining prey resources for the Crescent Island colony may have driven the relationship between productivity and timing of nest initiation, it is not possible to determine causality from this study.

The lack of a negative effect of nest density on productivity in this study suggests that high-density nesting does not incur immediate reproductive costs in Caspian terns, despite the increased potential for encounters with aggressive conspecifics. In order to assess the generality of our results at Crescent Island in 2001, we compared overall fledging success, nest density, breeding chronology,

and size of Caspian tern colonies in the Columbia River during 1999-2001 (Roby et al. 2002, D.D. Roby, unpubl. data). We used multiple linear regression to assess the relative effects of nest density (nests/m²), breeding chronology (the date that the first egg was observed at each colony), and colony size (number of breeding pairs) on fledging success (number of fledglings/pair) of Caspian terns at Crescent Island during 2000-2001, Rice Island during 1999-2000, and East Sand Island during 1999-2001. There were no significant relationships between nest density ($P = 0.73$), breeding chronology ($P = 0.95$), or colony size ($P = 0.80$) and fledging success (log-transformed) for the seven colony-years included in the analysis. This was the case whether all variables were included in the regression analysis or independent variables were examined individually.

The lack of a relationship between nest density and productivity across colonies supports the results presented in this study. The lack of an association between breeding chronology and fledging success is contrary, however, to the marked negative relationship between chronology of individual Caspian tern nests and productivity observed at Crescent Island. This may be due to differences in breeding synchrony among colonies, which could affect the relationship between timing of breeding and productivity. We included colony size in this analysis in order to account for large differences in the number of breeding pairs at these colonies (range = 548-8,900 pairs); it is interesting to note that these differences in colony size did not contribute directly to observed differences in productivity. Other potentially important differences among these colonies include: different species of avian nest predators present at the colony, differences in disturbance and predation rates, and differences in behavior of young at the colony due to differences in colony size and disturbance rates.

The absence of any significant relationships between nest density, timing of breeding, or colony size and productivity may have been a result of a lack of statistical power, given a high degree of variability in the data and a small sample

size ($N = 7$ colony-years). This is supported by the fact that only a small amount of variation in fledging success was described by the multiple linear regression model ($R^2 = 14.1\%$). The inclusion of additional data on Caspian tern colonies in the Columbia River in future years may improve the resolution of these relationships. Nevertheless, the results presented here on the effects of individual variation in nest density on productivity of Caspian terns at Crescent Island, and the effects of overall nesting density on total fledging success of Caspian tern colonies in the Columbia River can provide useful guidelines for management of Caspian tern nesting habitat.

Our results indicate that variation in individual nest densities within the range observed at Crescent Island ($0.25\text{-}1.5$ nests/m²), or the range of overall nest densities observed at colonies in the Columbia River ($0.25\text{-}1.0$ nests/m²) do not affect productivity of Caspian terns. This information may be helpful for natural resource managers deciding minimum area requirements for breeding Caspian terns at managed colony sites (e.g., at East Sand Island; Roby et al. 2002). Our data suggest that if colony area requirements are planned so that nest densities are maintained within the range observed at Crescent Island, density alone is not likely to affect the reproductive success of Caspian terns.

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Chapter 4

CASPIAN TERN PREDATION ON JUVENILE SALMONIDS
IN THE MID-COLUMBIA RIVER

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and Ken Collis

ABSTRACT

We investigated Caspian tern (*Sterna caspia*) predation on juvenile salmonids (*Oncorhynchus* spp.) in the mid-Columbia River in 2000 and 2001. We used a bioenergetics modeling approach to estimate consumption of juvenile salmonids and other forage fish by Caspian terns nesting at Crescent Island, WA, located below the confluence of the Snake and Columbia rivers. We also examined the distribution and habitat use of foraging terns near Crescent Island. Caspian terns have been managed in the Columbia River estuary to reduce predation rates on ESA-listed stocks of salmonids, but predation by Caspian terns nesting further upstream at Crescent Island has not yet been quantified. The predominant prey type in the diet of Crescent Island terns was juvenile salmonids; estimated consumption was 465,000 juvenile salmonids (95% CI: 382,000-547,000) during the 2000 breeding season, and 679,000 juvenile salmonids (95% CI: 533,000-825,000) during the 2001 breeding season. Densities of foraging terns were higher along the Walla Walla River, at certain ponds, and near McNary Dam, compared to river channel or shallows habitat on the Columbia and Snake rivers. Although the highest densities of foraging terns were observed on the Walla Walla River, a small tributary of the Columbia River, the estimated proportion of use by foraging terns was less than 20%. Total salmonid predation by Crescent Island Caspian terns was less than that reported for some actively-managed predators in the Columbia River (i.e., Caspian terns nesting in the Columbia River estuary and northern pikeminnow [*Ptychocheilus oregonensis*] in the John Day Reservoir), but more than that reported for others (i.e., gulls [*Larus* spp.] foraging at Wanapum Dam). State, federal, and tribal natural resource managers will use the results presented in this study to decide whether management of Caspian terns nesting at Crescent Island is warranted.

INTRODUCTION

The decline of anadromous salmonids (*Oncorhynchus* spp.) in the Columbia River basin over the last century and a half has prompted state, federal, and tribal resource managers to investigate a multitude of strategies for promoting salmon recovery (Lichatowich 1999). More than half of the 20 evolutionarily significant units (ESUs) of salmonids in the basin are currently listed under the U.S. Endangered Species Act (ESA; NMFS 2002), and all others have experienced major declines. While much of the focus of salmon restoration has been on the “four H’s” (improvement of freshwater and estuarine Habitat, increasing survival through the Hydrosystem, regulating human Harvest, and modifying Hatcheries [NRC 1996]), reducing the impacts of predation by marine mammals, fish, and birds on salmon survival has also been considered an important restoration strategy. In the Columbia River, predation on juvenile salmonids by piscivorous fish has been investigated in detail (Rieman et al. 1991), and resulted in an extensive management program to control losses of smolts to predation by northern pikeminnow (*Ptychocheilus oregonensis*; Beamesderfer et al. 1996, Friesen and Ward 1999).

Studies of piscivorous birds in other river systems have demonstrated that avian predators can have major impacts on survival of juvenile salmonids (e.g., Wood 1987, Kennedy and Greer 1988, Feltham 1995). In the Columbia River basin, avian predation has also been investigated as an important source of mortality to juvenile salmonids (Ruggerone 1986, York et al. 2000). Evidence of juvenile salmonid consumption by ring-billed gulls (*Larus delawarensis*) at Wanapum Dam (Ruggerone 1986) and Priest Rapids Dam (York et al. 2000) prompted the elimination of a ring-billed gull colony on Cabin Island, WA (Pochop et al. 1998), and the initiation of a culling program to reduce numbers of gulls foraging at these mid-Columbia River dams (C. Thompson, WDFW, pers.

comm.). In the lower Columbia River, evidence of predation on threatened and endangered salmon ESUs by piscivorous birds prompted federal agencies to investigate the effects of avian predation on out-migrating juvenile salmonids (NMFS 1995). Caspian terns (*Sterna caspia*) breeding in the Columbia River estuary were of particular concern because of growing numbers and the large proportion of juvenile salmonids in their diet (Collis et al. 2002). Researchers reported that Caspian terns nesting in the estuary consumed an estimated 9.1-15.7 million juvenile salmonids during the 1998 out-migration (approximately 13% of the number of juvenile salmonids to reach the estuary; Roby et al. 2003), and the decision was made to manage this tern population in order to reduce its impact on the survival of juvenile salmonids (USACE 1999, Roby et al. 2002).

While detailed studies of Caspian tern predation on juvenile salmonids have been conducted in the Columbia River estuary since 1997 (Collis et al. 2001, Collis et al. 2002, Roby et al. 2002, Roby et al. 2003), predation rates by Caspian terns breeding at colonies in the mid-Columbia River have not yet been quantified. These colonies are of concern to fisheries managers because data collected in 1997 and 1998 suggested that terns nesting on islands in the mid-Columbia River foraged primarily on juvenile salmonids (Collis et al. 2002).

We investigated salmonid predation by Caspian terns breeding 510 km (317 miles) upstream from the mouth of the Columbia River, at Crescent Island in 2000 and 2001. This study focused on the Crescent Island tern colony because the majority of Caspian terns nesting on islands in the mid-Columbia River nested at this site during the study period. In 2000, Caspian terns also nested at Three Mile Canyon Island in the mid-Columbia River (about 275 pairs); however, Caspian terns abandoned this site due to mink predation midway through the breeding season (see Chapter 2). In 2001, there were small numbers of Caspian terns nesting on Miller Rocks in the mid-Columbia River, but the size of this

colony likely did not exceed 20 pairs (D.P. Craig, Willamette University, pers. comm.).

The number of Caspian terns nesting at the Crescent Island colony was less than one-tenth the number of terns nesting in the Columbia River estuary during the study period (Roby et al. 2002, see Chapter 2). The Crescent Island colony has remained relatively stable over the past six years, although it increased by 26% between 2000 and 2001, from 548 to 688 breeding pairs (see Chapter 2). The diet of Caspian terns nesting at Crescent Island consisted mostly of juvenile salmonids (61% of prey items in 2000, and 68% in 2001; see Chapter 2). We used a bioenergetics modeling approach to quantify the numbers of out-migrating juvenile salmonids consumed by Caspian terns nesting at Crescent Island in 2000 and 2001, and investigated the distribution and habitat use of foraging terns from the Crescent Island colony.

Bioenergetics modeling was first used by Wiens and Scott (1975) to estimate prey consumption by fish-eating birds, and has since been used with a variety of avian species in both freshwater and marine systems (e.g., Furness 1978, Glahn and Brugger 1995, Madenjian and Gabrey 1995, Derby and Lovvorn 1997). The technique combines data on predator energy requirements with information on energy contribution of prey items to generate estimates of prey consumption. Bioenergetics modeling has been used in the Columbia River estuary to develop estimates of juvenile salmonid consumption by Caspian terns (Roby et al. 2003), the results of which have prompted management of terns in the estuary (Roby et al. 2002). In this study, we developed a bioenergetics model of prey consumption at Crescent Island based largely on the model used by Roby et al. (2003) and outlined in Figure 4.1. Estimates of juvenile salmonid consumption generated from this model will provide state, federal, and tribal resource managers with information necessary to assess if management action is warranted for Caspian terns at this site.

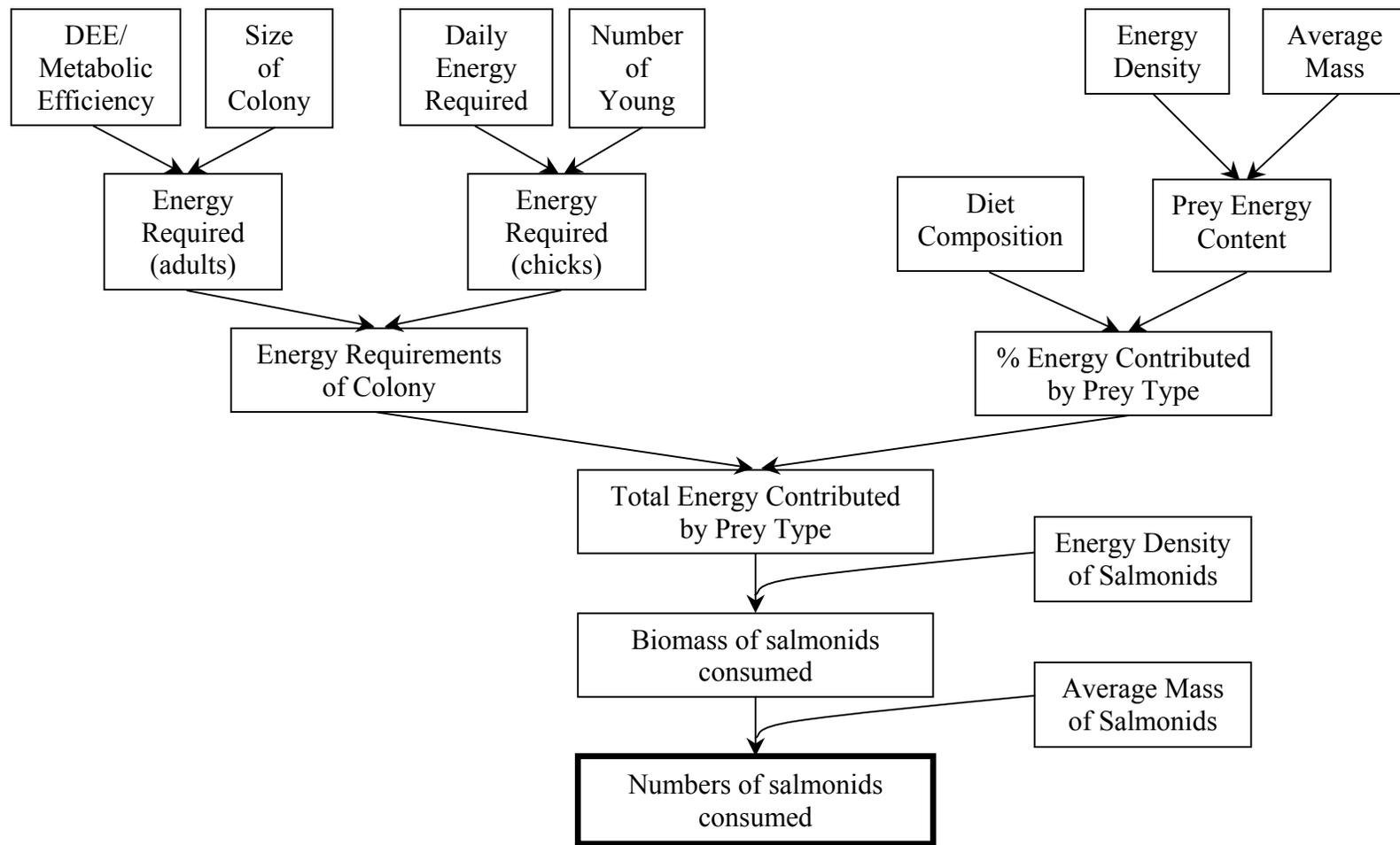


Figure 4.1. Schematic diagram of bioenergetics model used to estimate consumption of juvenile salmonids by Caspian terns nesting at Crescent Island in the mid-Columbia River.

We investigated the distribution and habitat use of foraging Caspian terns near Crescent Island in order to increase understanding of how terns exploit forage fish resources, especially out-migrating juvenile salmonids in the mid-Columbia River. We examined the relationship between densities of foraging terns and habitat type in order to determine if Caspian terns exhibited preferences for particular habitats where juvenile salmonids or other prey might be more available. We also estimated the relative proportions of foraging terns that used each habitat type throughout the study region. Finally, we examined the relationship between numbers of foraging terns and certain environmental factors to further aid in our understanding of the foraging behavior of Caspian terns nesting at Crescent Island. The environmental factors used in this analysis were chosen because they have been shown to affect foraging behavior in other terns (Dunn 1973, Burger 1982, Reed and Ha 1983, Sagar and Sagar 1989) and piscivorous birds (Grubb 1977, Bovino and Burt 1979). These results may shed light on the factors that influence predation rates on out-migrating juvenile salmonids by Caspian terns in the mid-Columbia River.

METHODS

STUDY AREA

We studied Caspian terns breeding at Crescent Island (46.094°N, 118.929°W) in 2000 and 2001. Crescent Island is a comma-shaped dredge-spoil island of 3.2 hectares located in the McNary Pool of the Columbia River, Washington, USA. Caspian terns colonized the island soon after its creation in 1985 (Ackerman 1994), and nest in association with California gulls (*Larus californicus*) on the northeastern side of the island; small numbers of ring-billed gulls also nest on the island. In 2000 and 2001, the colony of Caspian terns on

Crescent Island was the largest for this species in interior Washington and Oregon (see Chapter 2).

ENERGY REQUIREMENTS OF THE COLONY

Colony Size

Colony size was estimated for each two-week period of the 2000 and 2001 breeding seasons because the structure of the bioenergetics model was based on two-week intervals. The total number of adults present at the colony was counted from an observation blind at least once per week throughout each breeding season, and then averaged over each two-week period ($N_{\text{adults}}[t]$). Because maximum colony attendance was observed during late incubation ($N_{\text{max adults}}$), the numbers of tern nests counted during this two-week period were also averaged. This figure was multiplied by two to estimate the maximum number of individuals associated with the Crescent Island colony ($N_{\text{max ind}}$). We then adjusted this figure to determine the total number of individuals associated with the colony for each two-week period ($N_{\text{ind}}[t]$) during each breeding season:

$$N_{\text{ind}}[t] = \frac{N_{\text{max ind}} * N_{\text{adults}}[t]}{N_{\text{max adults}}},$$

We assumed that during late incubation, when maximum colony attendance was observed, all birds at the Crescent Island colony were actively breeding (either incubating/brooding or attending a nest). This assumption was supported by the absence of terns in sub-adult plumage either on- or off-colony, as well as a lack of terns roosting at the colony during late incubation that were not engaged in breeding activities.

Energy expenditure of adults

We used measurements of daily energy expenditure (DEE; kJ/day) obtained for free-ranging Caspian terns breeding at Rice Island in the Columbia River estuary in 1997 and 1998 (Roby et al. 2003) to estimate DEE of Caspian terns breeding at Crescent Island in 2000 and 2001. These measurements were obtained using the doubly labeled water technique (Lifson and McClintock 1966, Speakman 1997); the methodology is described in detail by Roby et al. (2003). Briefly, adult terns nesting at Rice Island were captured during late incubation or early chick-rearing, injected with isotopically-labeled water ($D_2^{18}O$), held until an initial, equilibrated blood sample was drawn, and then recaptured or lethally collected 24-48 hours later to obtain a final blood sample. Blood samples were analyzed for deuterium and oxygen-18 in the lab of G. H. Visser at the Centre for Isotope Research, University of Groningen, The Netherlands. We assumed that DEE of Caspian terns breeding in the Columbia River estuary would be similar to that of Caspian terns breeding at Crescent Island, and that DEE of terns during late incubation/early chick-rearing was representative of average adult DEE throughout the breeding period. Directly measuring DEE of Caspian terns breeding at Crescent Island was not feasible because of the relatively small size of the colony (compared to the Rice Island colony in 1997 and 1998) and the potential impact of such work on nesting success.

Metabolic efficiency of adults

We used assimilation efficiency to approximate the metabolic efficiency of adult Caspian terns, an approach used in many bioenergetic studies (Miller and Reinecke 1984). We assumed that the metabolic efficiency of Caspian terns was 0.75 with a standard error of 0.025, based on reviews of assimilation efficiency in birds (Castro et al. 1989, Karasov 1990), and following Roby et al. (2003). Average adult DEE was divided by this estimate of metabolic efficiency to

calculate daily energy requirements of adult Caspian terns breeding at Crescent Island, and then multiplied by colony size (number of adults) to obtain total adult energy requirements.

Numbers of young

In order to simplify the modeling of chick energetics, all chicks were assumed to be perfectly synchronous with the timing of peak hatching observed at Crescent Island. The number of chicks on the Crescent Island colony was then estimated for each day between the median hatch date and the average departure date for Caspian tern fledglings at this colony. We assumed that chicks departed from the colony one week after the average fledging age of 37 days (Cuthbert and Wires 1999). This was supported by observations of fledglings at monitored nests on Crescent Island, and by observations of fledgling behavior in the Columbia River estuary (Roby et al. 2003). We estimated the number of chicks present on each day during the chick-rearing period from counts of the number of hatchlings and the number of fledglings, and assuming exponential decline in the interim. The number of hatchlings was determined by multiplying the number of breeding pairs by an estimate of the number of chicks per nest at hatching, determined by observing nest contents from a blind for a randomly-selected subset of nests. The number of fledglings was estimated by averaging a series of counts of the number of chicks present on-colony spanning the period from first fledging to two weeks later.

Energy requirements of chicks

We used estimates of daily energy requirements for individual Caspian tern chicks calculated by Roby et al. (2003) for the period of time that chicks were assumed to be present at Crescent Island (from median hatch date to average departure date). See Roby et al. (2003) for a detailed description of methodology.

Daily energy requirements of individual chicks were multiplied by estimates of numbers of young to determine the total energy requirements of Caspian tern chicks at the Crescent Island colony. This was then combined with estimates of adult energy requirements to estimate the total energy requirements of the Caspian tern colony at Crescent Island.

ENERGY CONTRIBUTIONS OF PREY

Diet composition

Percent composition of prey was determined by observing bill loads of adult terns (fish held crosswise in the bill) at the Crescent Island colony from an observation blind and visually identifying prey items to the lowest distinguishable taxa using binoculars and spotting scopes (see Collis et al. 2002). Diet composition was then calculated for each two-week period used in the bioenergetics model structure. In 2000, diet observations were not made during the earliest two-week time period, so it was assumed that diet composition was the same as the next time period. The number of identified bill loads per two-week time period was usually about 250 fish, and ranged between 11 and 391 fish.

In 2001, an effort was made to identify prey to species, where possible, and to identify salmonids as either steelhead (*Oncorhynchus mykiss*) or 'other salmonids' (chinook salmon, *O. tshawytscha*; coho salmon, *O. kisutch*; or sockeye salmon, *O. nerka*), so that differences in average mass and/or energy density of prey species could be accounted for in our analysis. Steelhead were distinguished from 'other salmonids' by the shape of the anal and caudal fins, coloration and speckling patterns, shape of parr marks, or a combination of these characteristics. We were not able to distinguish among 'other salmonids,' so these species were grouped in our analysis. When prey could only be identified to family (when species distinctions were attempted), species composition was extrapolated based

on observations where prey were identified to species for that time period. In 2000, when prey items were only identified to family, species composition was assumed to be the same as in 2001 during the corresponding time period. In addition, there were a number of cases where we were only able to identify prey items as non-salmonids (this was less prevalent in 2001 because of increased familiarity with prey types). In these cases, a weighted average was used to estimate the energy density and average mass of this category, based on the relative proportions of all identified non-salmonid prey types in that two-week time period.

We assumed that prey items brought back to the colony by breeding adults represented the overall diet of Caspian terns nesting at this site, an assumption supported by observations in the Columbia River estuary that prey composition in gut contents did not differ significantly from prey composition of bill loads (Collis et al. 2002). In addition, because salmonids comprised the majority of the diet, we conducted trials before and after the 2001 breeding season to assess our accuracy in distinguishing steelhead from ‘other salmonid’ species, using samples of juvenile salmonids collected in the Columbia River estuary.

Average mass of prey items

We calculated average mass of prey types by estimating the lengths of fish transported to the tern colony by breeding adults, and incorporating these data into length-mass regressions developed for each prey type. Length estimation was based on relating the length of the fish to the average length of a Caspian tern bill, from the gape to the tip (8.5 cm). Again, because salmonids comprised such a large portion of the tern diet, the accuracy of our length estimation for salmonids was assessed by conducting trials with samples of juvenile salmonids collected in the Columbia River estuary.

Length-mass regressions for each prey type were developed by sampling prey items found in the diet of Crescent Island terns in the mid-Columbia River. The majority of the samples were obtained during 30 May-13 June 2001, between river kilometer 439 and 536 (river mile 273 and 333) of the Columbia River, in conjunction with a study conducted by the Oregon Department of Fish and Wildlife. Fish were electro-shocked at night, from boats, and placed in a holding tank on the vessel until processed. Samples were either measured for total length (± 1 mm) and weighed using a spring-loaded Pesola scale (± 0.5 g for fish < 60 g, ± 1 g for larger fish) and released, or collected for analysis of energy content (see below). Additional samples were collected by hook-and-line at known tern foraging sites near Crescent Island. These data were then used to develop power regressions for each prey type, from which estimates of average mass were calculated.

Juvenile salmonids were not collected as part of this study in order to minimize mortality to threatened and endangered stocks. Instead, we used the lengths and masses of juvenile salmonid samples obtained by lethally collecting adult Caspian terns in the Columbia River estuary in 2000 and 2001 (D.D. Roby, unpubl. data) to develop length-mass regressions for steelhead and ‘other salmonid’ species. Only intact fish collected as dropped bill loads from adult terns were used in this analysis. The regression for ‘other salmonid’ species was based on pooled samples of coho and chinook salmon (individual regressions of these species did not differ significantly; $P = 0.39$, from a test for difference in slopes). Sockeye salmon were not included in this regression because this species did not appear in bill loads collected from Caspian terns in the estuary in 2000 or 2001, presumably because they do not comprise a substantial portion of tern diets (Collis et al. 2001).

Lethal sampling techniques used in the Columbia River estuary (Roby et al. 2003) provided a direct measurement of the average mass of each prey type

transported to the colony, and so may be more accurate than the methods we used to estimate average mass of prey types at Crescent Island. In order to improve the accuracy of the average mass estimation for prey items at Crescent Island, we used the range of masses from dropped fish collected in the Columbia River estuary as data limits, and excluded estimated masses for prey items at Crescent Island that were outside of these limits.

Energy density of prey

We analyzed whole fish, collected by methods described above, in the lab to determine mean energy density of each prey type. Energy density of individual fish was estimated based on biochemical composition as determined by proximate composition analysis and published energy equivalents for lipid and protein fractions (see Anthony et al. 2000 for detailed methods), and then averaged by prey type.

Because juvenile salmonids were not collected near Crescent Island, we used energy densities derived from salmonids collected in the Columbia River estuary (Roby et al. 2003). Energy densities of coho and chinook salmon were averaged together to determine mean energy density of ‘other salmonid’ species. In addition, we included energy density data collected in the Columbia River estuary (Roby et al. 2003) to determine mean energy densities for peamouth (*Mylcheilus caurinus*) and lamprey (Petromyzontidae) because we were not able to collect sufficient samples of these prey types near Crescent Island.

Total energy content of each prey type was then estimated by multiplying average energy density times average mass for that prey type. This was then combined with data on diet composition for each two-week period, described above, to determine the proportion of total energy contributed by each prey type throughout the breeding season.

BIOENERGETICS MODEL STRUCTURE

We modified a bioenergetics model described in Roby et al. (2003) to estimate consumption of juvenile salmonids and other prey types by Caspian terns nesting at Crescent Island in 2000 and 2001. The model was constructed in Visual Basic 6.0, and the general structure is outlined in Figure 4.1. Data on energy expenditure and metabolic efficiency of adults were expanded by estimates of colony size, and combined with data on numbers of young and energy requirements of chicks to calculate total energy requirements for the colony in each year. Diet composition data were combined with estimates of average mass and mean energy density of prey to determine the percent energy contribution of each prey type. This was then multiplied by the total energy requirements of the colony to obtain the total energy contribution of each prey type. Estimates of mean energy density and average mass were then used again to convert the energy contribution of each prey type into estimates of biomass and numbers consumed.

For the purpose of the model, the breeding season was broken into two-week periods, during which colony size and diet composition were estimated. There were 8 two-week periods used in 2000 (3 Apr-23 Jul) and 9 in 2001 (2 Apr-5 Aug), which reflected when terns were present at the Crescent Island colony during those years. Confidence intervals for output estimates were obtained using a Monte Carlo simulation technique (Furness 1978), following Roby et al. (2003). We ran 1000 simulations of the model for each year, from which estimates of prey consumption were obtained. It was assumed that all inputs followed a normal distribution, and that input values were independent.

FORAGING DISTRIBUTION AND HABITAT USE

We counted Caspian terns along a survey route that consisted of 20 off-colony sites on the mid-Columbia River, lower Snake River, Walla Walla River,

and small ponds located near the Columbia River (Figure 4.2). We determined the distribution of foraging terns in the study area early in the 2000 breeding season, so that we did not select sites that were outside the foraging range of Caspian terns nesting at Crescent Island; the maximum distance to a surveyed site was 42 km. There was another Caspian tern colony in the mid-Columbia River during this study, at Three Mile Canyon Island; however, this colony was abandoned midway through the 2000 breeding season due to mink predation (see Chapter 2) and was located approximately 97 km down-river from Crescent Island. Thus it was assumed that all foraging terns observed at the 20 selected sites were associated with the Crescent Island colony. Sites were selected to balance the number of sites up-river and down-river from Crescent Island, and to cover a range of habitat types (Figure 4.2). Sites were usually visited twice each week, and the maximum number of foraging terns observed during a 10-minute observation period was recorded at each site. Terns were defined as foraging if they actively engaged in foraging activities (i.e., plunge-diving, scanning the water for prey, repeatedly flying low over an area of water). Time of day at the start of the observation period (PDT), cloud cover (clear or cloudy), and wind speed (using the Beaufort Wind Scale; BWS) were also recorded. The first site visited on a given sampling day was chosen at random; each subsequent site was then visited in a specified order, so that all sites could be visited in a single day.

The area of each site was defined by landmarks on the river, and was limited to a distance where observers could distinguish between foraging terns and gulls using binoculars or spotting scopes (< 1,500 m). Maps of each site were downloaded into ArcView® software (Environmental Systems Research Institute, Inc.), and polygons were constructed to reflect site boundaries. Site areas were then determined from these polygons and used to calculate the density of foraging terns at each site (terns/km²). This allowed comparisons to be made among sites that differed greatly in area (see Figure 4.2).

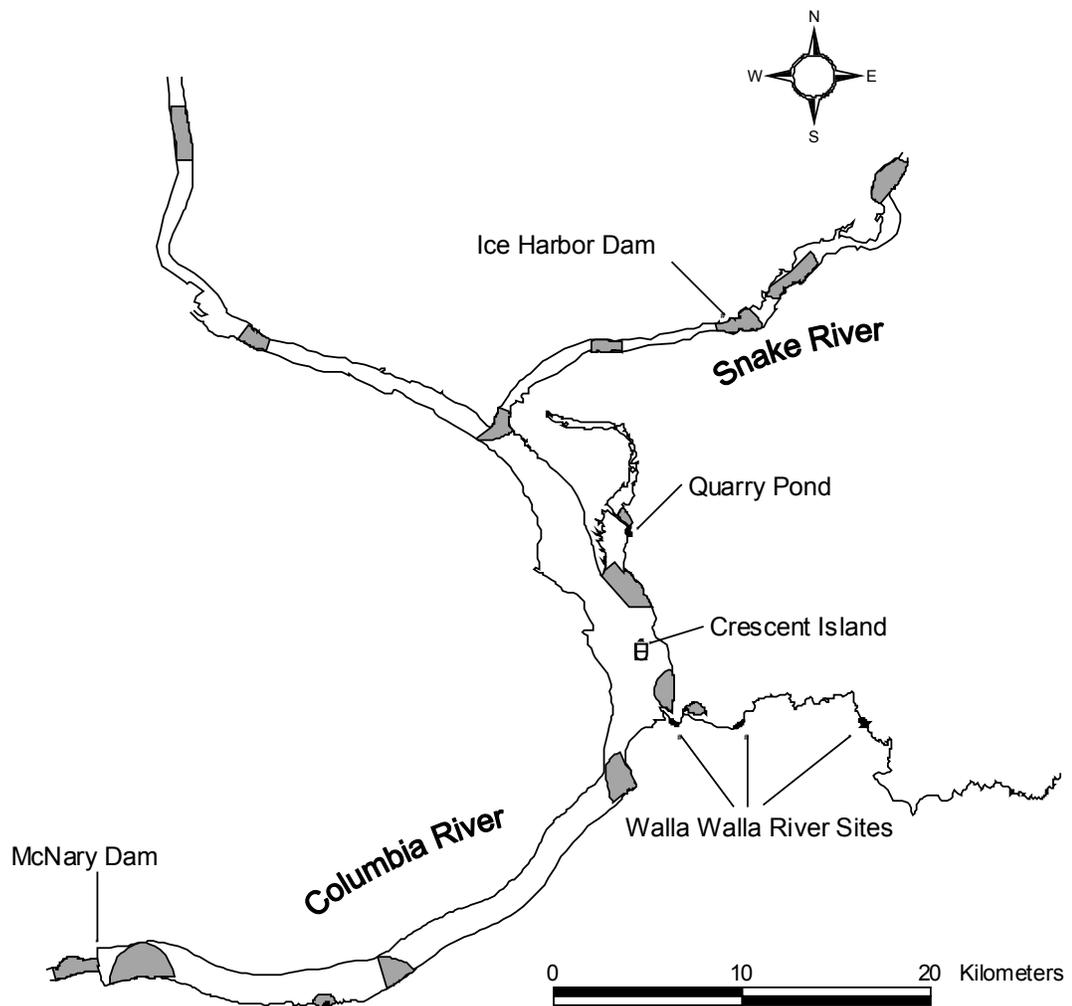


Figure 4.2. Locations of 20 off-colony sites near Crescent Island where numbers of foraging Caspian terns were observed during the 2000 and 2001 breeding seasons.

The habitat type of each site was designated as one of five categories: (1) channel, where most of the observation area covered deep water shipping channels on the mainstem Columbia or Snake rivers; (2) shallows, defined as rocky or sandy shallow areas along the Columbia or Snake rivers; (3) sites along the Walla Walla River, a small tributary of the Columbia River; (4) ponds located near the Columbia, Snake, and Walla Walla rivers; and (5) the vicinity of hydroelectric dams, specifically McNary Dam on the Columbia River and Ice Harbor Dam on the Snake River. We estimated total area of each habitat type available to Caspian terns within the study region using digital maps in ArcView® software. The study area was defined by the furthest sampling site from the Crescent Island colony (42 km), so potential foraging habitat was considered all aquatic habitat 42 km upstream from Crescent Island on the Columbia, Snake, and Walla Walla rivers and 42 km downstream on the Columbia River. All ponds near these expanses of river (< 5 km) were considered potential foraging habitat and included in the total area estimation for this habitat type; we did not include ponds found further from the river because we did not sample remote ponds in this study. Channel and shallows on the mainstem Columbia and Snake rivers were grouped as a single habitat type for this portion of the analysis because there was no evidence of a difference between these two habitat types in use by Caspian terns (see Results).

Densities of foraging terns at each site were averaged across the breeding season and then grouped by habitat type for each year. Group differences were tested using non-parametric Kruskal-Wallis tests. In order to account for differences in the distance to the Crescent Island colony among sites, all observations of the densities of foraging terns were incorporated into a Poisson log-linear regression model. Data were first tested for serial correlation because sites were visited in spatial and temporal order. There was no evidence of serial correlation in either 2000 ($Z = -1.0756$, $P = 0.14$) or 2001 ($Z = -1.0353$, $P = 0.15$),

so we proceeded with regression analysis. We compared a model that assessed the effects of habitat and distance alone on densities of foraging terns, to one that also incorporated among-site variability, and reported the results of both these models. Models were compared using a drop-in-deviance F -test, which accounted for extra-Poisson variation. Channel habitat was chosen as a reference level for this analysis, and relative effects of the other four habitat types (compared to channel habitat) on densities of foraging terns were assessed. P -values reported for relative effects of habitat type were derived from Wald's tests for single coefficients, after accounting for extra-Poisson variation, and are approximate. Average densities of foraging terns in each habitat type (with channel and shallows on the Columbia and Snake rivers grouped together) were multiplied by the total area of each habitat type available within the study region (described above) to estimate the proportions of foraging terns that used each habitat type within the study region.

Numbers of foraging terns were also grouped by environmental variables, and group differences were tested using either Wilcoxon rank-sum or Kruskal-Wallis tests. Time of day was broken into 3 categories: morning (7:00-11:59), afternoon (12:00-16:59), or evening (17:00-20:59), and cloud cover was characterized as either clear (with shadows present) or cloudy (sun occluded by clouds; Grubb 1977, Bovino and Burt 1979). Finally, wind speed was categorized as either calm (BWS: 0-1) or windy (BWS: ≥ 2 ; Bovino and Burt 1979). Estimates are mean \pm SE and all P -values reported are two-sided.

RESULTS

ENERGY REQUIREMENTS OF THE COLONY

The average number of Caspian tern nests counted during late incubation at Crescent Island increased from 548 (SD = 7.41, N = 4) in 2000 to 664 (SD =

20.6, N = 3) in 2001. The average numbers of adults counted in each two-week time period during the 2000 and 2001 breeding season are presented in Figure 4.3. Average DEE of adult Caspian terns was assumed to be 1,040 kJ/day (SD = 209, N = 24), and metabolic efficiency was assumed to be 0.75 (SD = 0.025, N = 1; Roby et al. 2003). In 2000, the average number of chicks/nest at hatching was 1.5 (SD = 0.82, N = 166), and the average total number of fledglings on the colony was 356 (SD = 124, N = 7). In 2001, the number of chicks/nest at hatching averaged 1.9 (SD = 0.74, N = 181), and the average total number of fledglings was 637 (SD = 127, N = 5). Total metabolizable energy requirement of a Caspian tern chick from hatching to departure from the colony was estimated as 19.2 MJ (SD = 10.5, N = 1) using allometric equations, with daily requirements ranging from 192 kJ chick⁻¹ day⁻¹ at hatch to 707 kJ chick⁻¹ day⁻¹ at fledging age (Roby et al. 2003).

Our estimates of the total energy requirements of the Caspian tern colony at Crescent Island in 2000 and 2001 are presented in Table 4.1. The 35% increase in estimated energy requirements from 2000 to 2001 was due to the increase in both colony size and productivity. The number of nests counted during late incubation increased 21% from 548 to 664 pairs and average productivity increased 48% from 0.65 to 0.96 fledglings/nest. Energy requirements of chicks constituted 12.4% of total colony requirements in 2000, and 16.2 % in 2001. This is a higher proportion of energy required by young than that reported by Roby et al. (2003) for the Rice Island Caspian tern colony in the Columbia River estuary, and is mostly attributable to higher fledging success at the Crescent Island colony.

ENERGY CONTRIBUTIONS OF PREY

Salmonids were the predominant prey type in the diet of Caspian terns nesting at Crescent Island (61% in 2000, 68% in 2001; for more details on diet composition, see Chapter 2), and of the salmonid portion of the diet, species other

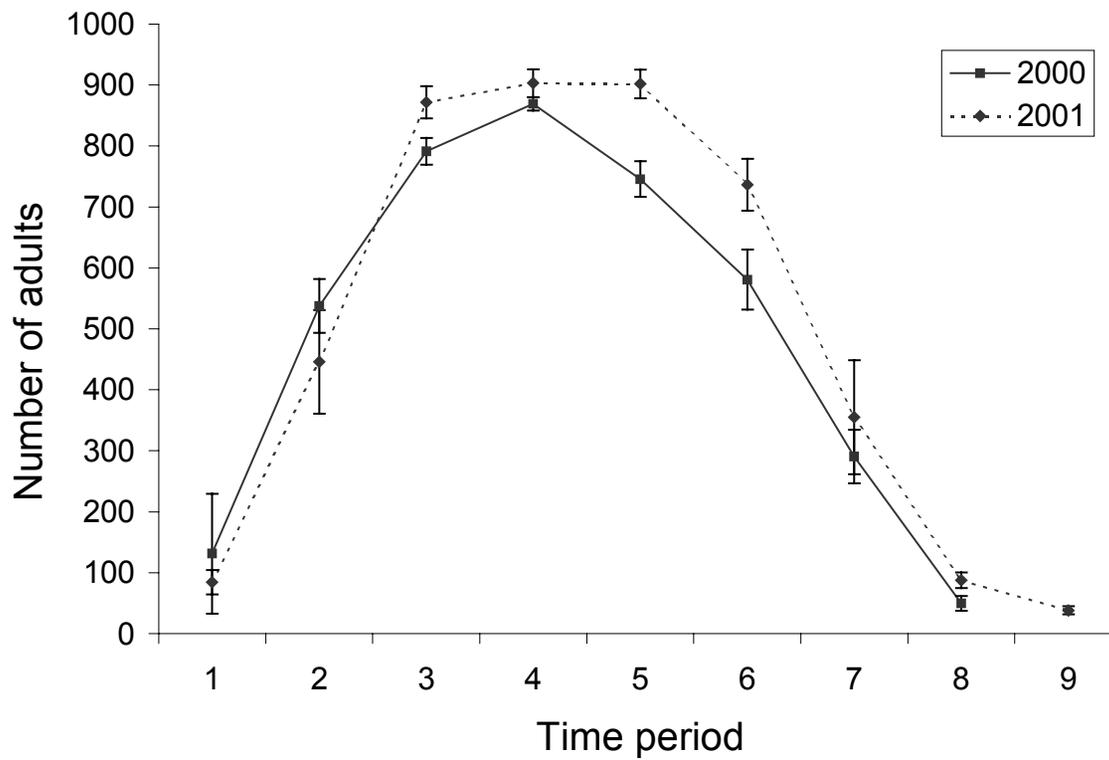


Figure 4.3. Average number of adult Caspian terns counted on-colony during each two-week period of the breeding season at Crescent Island in 2000 (3 Apr-23 Jul) and 2001 (2 Apr-5 Aug). Error bars represent standard error of the mean.

Table 4.1. Total energy requirements of the Caspian tern colony at Crescent Island in 2000 and 2001, and the percent energy contributed by prey type, as determined from a bioenergetics model. Energy requirements are mean (SD).

ENERGY REQUIREMENTS (10 ³ MJ)	2000	2001
Adults	97.8 (6.28)	125.9 (8.80)
Young	13.9 (7.45)	24.4 (12.3)
Total	111.7 (9.86)	150.3 (15.7)
% ENERGY CONTRIBUTION OF PREY		
All salmonids ¹	71.2	76.0
Steelhead ²	29.1	29.9
Other salmonids ³	42.1	46.1
Bass ⁴	4.35	4.47
Bluegill ⁵	4.34	3.83
Chiselmouth ⁶	0.76	0.91
Northern pikeminnow ⁷	0.11	0.12
Peamouth ⁸	2.31	4.52
Catfish ⁹	1.95	2.50
Lamprey ¹⁰	0.12	0.10
Sculpin ¹¹	0.27	1.28
Sucker ¹²	0.64	2.03
Yellow perch ¹³	1.11	1.21
Unidentified non-salmonids	12.8	3.06

¹Salmonidae; ²*O. mykiss*; ³*Oncorhynchus* spp.; ⁴*Micropterus* spp.; ⁵*Lepomis macrochirus*; ⁶*Acrocheilus alutaceus*; ⁷*Ptychocheilus oregonensis*; ⁸*Mylcheilus caurinus*; ⁹Ictaluridae; ¹⁰Petromyzontidae; ¹¹Cottidae; ¹²Catostomidae; ¹³*Perca flavescens*

than steelhead made up a greater proportion of the diet than did steelhead (Table 4.1, Figure 4.4). This was expected, given that three species (chinook, coho, and sockeye salmon) are included in this prey type. Our ability to distinguish steelhead from other salmonid species was at least 93% accurate, based on trials with salmonid specimens of known species collected in the Columbia River estuary. Salmonid lengths were underestimated by 4% in one trial, while in a second trial they were overestimated by 1%, so it does not appear that estimates of salmonid lengths were biased. Length-mass regressions developed from samples of fish collected in the mid-Columbia River and the Columbia River estuary are listed in Table 4.2, along with average masses calculated using length estimates of bill loads transported to the Crescent Island tern colony in 2001.

Mean energy densities of prey types determined from proximate composition analysis are also listed in Table 4.2 and range from 3.40 to 8.75 kJ/g wet mass. Steelhead had the greatest average mass per fish (61.1 g), but only the second highest energy content per fish (281.7 kJ). Catfish (Ictaluridae) had the greatest average energy content per fish in 2001 (352.6 kJ), due to a high average mass (40.3 g), and the highest mean energy density (8.75 kJ/g) of all prey items analyzed in this study or by Roby et al. (2003). In 2000, the average estimated mass of catfish brought back to the Crescent Island tern colony was lower (23.9 g), and so average energy content of individual catfish in that year (209.1 kJ) was not as high as that of steelhead.

The percent energy contribution of each prey type was determined by combining the above data on average energy content of each prey type with data on diet composition, and is presented in Table 4.1. Salmonids contributed the greatest percentage of the total amount of energy required by the Crescent Island colony (71.2% in 2000, 76.0% in 2001), with species other than steelhead contributing a greater proportion than steelhead (roughly 50% more in both

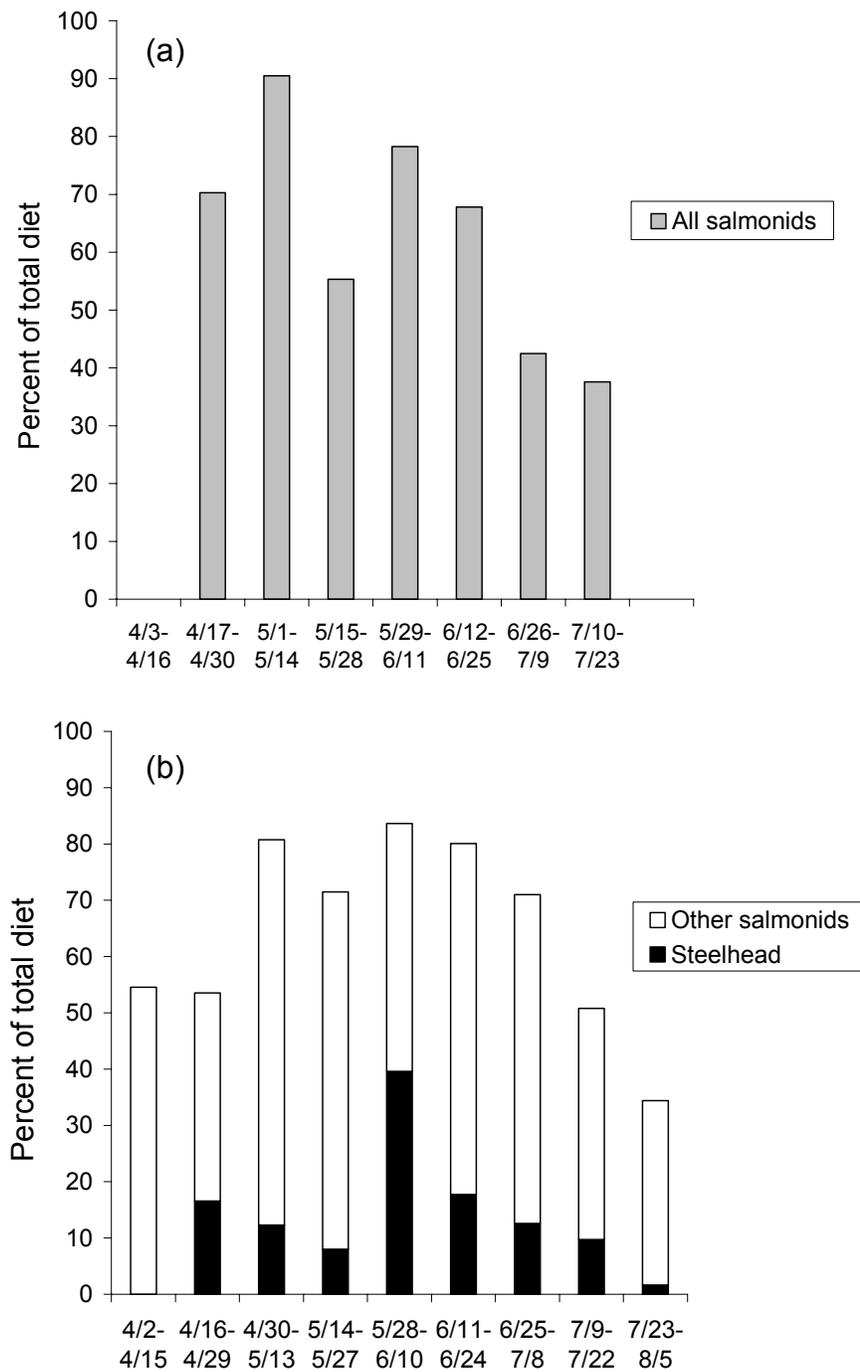


Figure 4.4. Percent salmonids in the diet of Caspian terns during each two-week period of the breeding season at Crescent Island in 2000 (a) and 2001 (b).

Table 4.2. Length-mass regressions (L = total length [cm]), average mass (g), energy density (kJ/g wet mass), and average energy content (mass x energy density) of prey items found in the diet of Caspian terns breeding at Crescent Island.

	L-M Regression			2001 Prey Mass (g)			Energy Density (kJ/g)			Energy Content (kJ)
	M =	R ²	N	Mean	SD	N	Mean	SD	N	
Steelhead ¹	0.0052*L ^{3.06}	0.64	39	61.1	18.1	233	4.61	0.86	12	281.7
Other salmonids ²	0.0248*L ^{2.55}	0.92	153	29.6	13.5	796	4.51	0.91	24	133.5
Bass ³	0.0109*L ^{3.05}	0.99	88	41.1	19.9	137	3.40	0.20	11	139.7
Bluegill ⁴	0.0046*L ^{3.60}	0.96	22	48.2	22.4	70	3.56	0.41	9	171.6
Chiselmouth ⁵	0.0094*L ^{2.98}	0.96	75	45.4	20.1	12	3.96	0.53	11	179.8
N. pikeminnow ⁶	0.0043*L ^{3.22}	0.99	11	25.0	10.6	4	4.65	0.48	5	116.3
Peamouth ⁷	0.0082*L ^{2.99}	0.98	15	21.8	13.4	116	5.72	1.37	13	124.7
Catfish ⁸	0.0207*L ^{2.74}	0.97	10	40.3 ¹³	13.4	25	8.75	0.89	4	352.6
Lamprey ⁹	0.0025*L ^{2.72}	0.77	11	5.45 ¹³	3.28	14	5.86	0.59	7	31.9
Sculpin ¹⁰	0.0065*L ^{3.27}	0.98	47	47.4 ¹³	14.5	24	3.74	0.55	12	177.3
Sucker ¹¹	0.0097*L ^{3.02}	0.98	91	37.6 ¹³	19.9	38	4.35	0.59	12	163.6
Yellow perch ¹²	0.0078*L ^{3.11}	0.98	46	32.5 ¹³	15.6	21	4.38	0.37	12	142.4

¹*O. mykiss*; ²*Oncorhynchus* spp.; ³*Micropterus* spp.; ⁴*Lepomis macrochirus*; ⁵*Acrocheilus alutaceus*; ⁶*Ptychocheilus oregonensis*; ⁷*Mylcheilus caurinus*; ⁸Ictaluridae; ⁹Petromyzontidae; ¹⁰Cottidae; ¹¹Catostomidae; ¹²*Perca flavescens*; ¹³Prey mass calculated separately in 2000. In all other cases, 2001 prey mass was used for both years because species distinctions were not made in 2000 (length estimates by family did not differ statistically in 2000 and 2001).

years). In 2000, unidentified non-salmonids contributed the next highest fraction, followed by bass (*Micropterus* spp.; 4.35%) and bluegill (*Lepomis macrochirus*; 4.34%). In 2001, greater familiarity with fish species left fewer non-salmonid prey items unidentified, and peamouth (*Mylcheilus caurinus*; 4.52%) contributed the next highest percentage of total energy requirements for Crescent Island terns. Other prey types contributing at least 2% of energy requirements in 2001 were bass, bluegill, catfish, suckers (Catostomidae), and unidentified non-salmonids (Table 4.1).

PREY CONSUMPTION

We estimated that Caspian terns breeding at Crescent Island consumed 25.0 MT (95% CI: 20.3-29.6 MT) of fish biomass in 2000, and 33.4 MT (95% CI: 26.2-40.6 MT) in 2001 (Table 4.3). Juvenile salmonids comprised the majority of prey biomass consumed, and we estimated that tern consumption of juvenile salmonids was 17.4 MT (95% CI: 14.2-20.5 MT) in 2000 and 25.1 MT (95% CI: 19.6-30.6 MT) in 2001. The larger size and productivity of the Crescent Island colony in 2001, combined with greater contribution of juvenile salmonids to the diet in that year, resulted in the 44% increase in biomass consumption of juvenile salmonids in 2001. Other prey types for which Crescent Island Caspian terns consumed more than 1.0 MT of fish biomass per year included: bass, bluegill, peamouth, suckers, and unidentified non-salmonids (Table 4.3).

We used data on average mass of prey types to convert estimates of biomass consumption into total numbers of prey consumed for each prey type. The estimated number of fish consumed by terns nesting at Crescent Island was 679,000 (95% CI: 552,000-806,000) in 2000, and 912,000 (95% CI: 718,000-1,104,000) in 2001 (Table 4.3). We estimated that Caspian terns nesting at Crescent Island consumed 465,000 juvenile salmonids (95% CI: 382,000-547,000) during the 2000 breeding season, and 679,000 juvenile salmonids (95%

Table 4.3. Estimates of prey consumption in units of biomass (MT) and total numbers (10^3) by Caspian terns nesting at Crescent Island in 2000 and 2001.

	2000			2001		
	Biomass	-----Numbers-----		Biomass	-----Numbers-----	
	Mean (MT)	Mean (10^3)	95% CI (10^3)	Mean (MT)	Mean (10^3)	95% CI (10^3)
All Prey	25.0	679	552-806	33.4	911	718-1104
All Salmonids¹	17.4	465	382-547	25.1	679	533-825
Steelhead ²	7.0	115	91.9-138	9.7	159	121-197
Other salmonids ³	10.3	350	289-410	15.4	520	410-629
Bass ⁴	1.4	34.6	25.2-44.0	2.0	47.8	35.7-59.9
Bluegill ⁵	1.4	28.2	23.1-33.3	1.6	33.7	27.0-40.3
Chiselmouth ⁶	0.2	4.7	3.1-6.4	0.3	7.6	4.9-10.3
N. pikeminnow ⁷	< 0.1	1.0	0.6-1.4	< 0.1	1.6	0.9-2.3
Peamouth ⁸	0.4	20.6	15.5-25.7	1.2	54.5	43.8-65.2
Catfish ⁹	0.2	10.3	8.6-12.0	0.4	10.7	7.6-13.8
Lamprey ¹⁰	< 0.1	4.3	3.2-5.4	< 0.1	4.9	3.7-6.0
Sculpin ¹¹	0.1	2.3	1.7-2.9	0.5	10.8	8.3-13.4
Sucker ¹²	1.6	3.9	2.9-4.9	0.7	18.6	13.9-23.3
Yellow perch ¹³	0.3	10.4	8.5-12.2	0.4	12.7	10.6-14.8
Unidentified non-salmonids	3.3	94.0	74.3-114	1.0	29.5	24.3-34.7

¹Salmonidae; ²*O. mykiss*; ³*Oncorhynchus* spp.; ⁴*Micropterus* spp.; ⁵*Lepomis macrochirus*; ⁶*Acrocheilus alutaceus*; ⁷*Ptychocheilus oregonensis*; ⁸*Mylcheilus caurinus*; ⁹Ictaluridae; ¹⁰Petromyzontidae; ¹¹Cottidae; ¹²Catostomidae; ¹³*Perca flavescens*

CI: 533,000-825,000) during the 2001 breeding season. The increase in number of juvenile salmonids consumed from 2000 to 2001 was due to a combination of factors. Both the number of breeding pairs and the number of young raised increased in 2001, resulting in greater energy requirements for the colony. In addition, the percent salmonids in the diet increased in 2001 (Figure 4.4; see Chapter 2), resulting in a greater energy contribution from salmonids during the 2001 breeding season. Caspian terns consumed fewer steelhead smolts compared to other salmonid species in both years (roughly 70% less; Table 4.3). Steelhead comprised 24.7% of total salmonids consumed by Caspian terns at Crescent Island in 2000, and 23.4% in 2001. Estimates of numbers of other types of fish consumed by Caspian terns breeding at Crescent Island are presented in Table 4.3.

FORAGING DISTRIBUTION AND HABITAT USE

There were significant differences in the densities of foraging terns observed in the five habitat types in both 2000 ($\chi^2_4 = 11.265$, $P = 0.02$) and 2001 ($\chi^2_4 = 12.705$, $P = 0.01$). Sites on the Walla Walla River had the highest densities of foraging terns in both years, followed by ponds and hydroelectric dams (Figure 4.5). After accounting for distance from the Crescent Island colony, densities of foraging terns were still significantly higher at sites on the Walla Walla River ($P < 0.0001$ in both 2000 and 2001), at dams ($P < 0.0001$ in both 2000 and 2001), and at ponds ($P = 0.0002$ in both 2000 and 2001) than at channel sites on the mainstem Columbia and Snake rivers. Densities of foraging terns did not differ significantly between shallows and channel habitat on the mainstem Columbia and Snake rivers in either 2000 ($P = 0.31$) or 2001 ($P = 0.27$). Distance from the Crescent Island colony, after accounting for habitat type, was not related to densities of foraging terns in 2000 ($P = 0.44$), but was negatively related in 2001

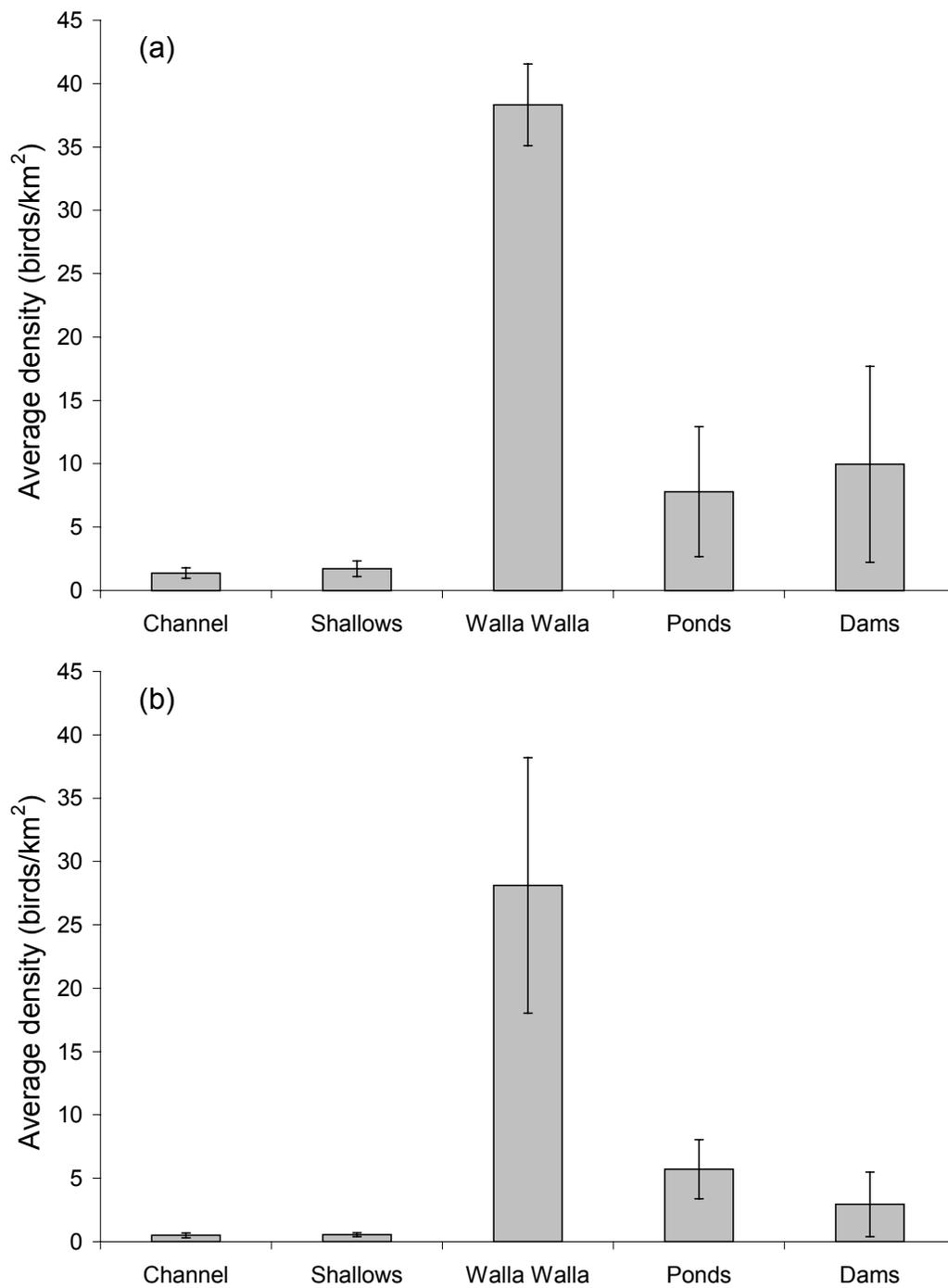


Figure 4.5. Average densities of foraging Caspian terns at sites grouped by habitat type near Crescent Island in 2000 (a) and 2001 (b). Error bars represent standard error.

($P = 0.01$). Accounting for among-site variation significantly improved the fit of the model in both 2000 ($P = 0.0009$) and 2001 ($P = 0.0001$).

After accounting for both among-site variation and distance from the Crescent Island colony, density of foraging terns was not significantly related to habitat type in 2000 ($P > 0.2$ for all four habitat types, relative to channel sites). In 2001, the Walla Walla River was the only habitat type that had significantly higher densities of foraging terns than channel habitat, after accounting for among-site variation and distance from the colony ($P = 0.004$; for all other habitat types $P > 0.1$). This result suggests that there was a great deal of variability among sites for the dam and pond habitat types (Figure 4.6), and that habitat type was not the strongest predictor of higher densities of foraging terns. Instead, terns may have been selecting particular sites within our habitat groupings, as opposed to the habitat type in general. For instance, higher densities of foraging terns were observed at Quarry Pond compared to other ponds, a difference that may be attributable to fish stocking activities by the State of Washington at this pond. In addition, higher densities of foraging terns were observed at McNary Dam compared to Ice Harbor Dam; this difference may be due to the absence of ‘bird wires’ at the former site. Bird wires are used to discourage piscivorous birds from foraging in the tailrace of dams and are present at Ice Harbor Dam, but not at McNary Dam.

We estimated that there was a total of 145 km² of mainstem habitat (channel and shallows) on the Columbia and Snake rivers within the study area (42 km up- and down-river of Crescent Island). Total foraging habitat available within the study area for other habitat types was much smaller. We estimated that there was a total of 6.3 km² of aquatic habitat near hydroelectric dams, 5.6 km² of pond habitat near the Columbia, Snake, and Walla Walla rivers, and 1.0 km² of habitat on the Walla Walla River; total area for these three habitat types was less than 10% of the total foraging habitat available within the study area. Based on

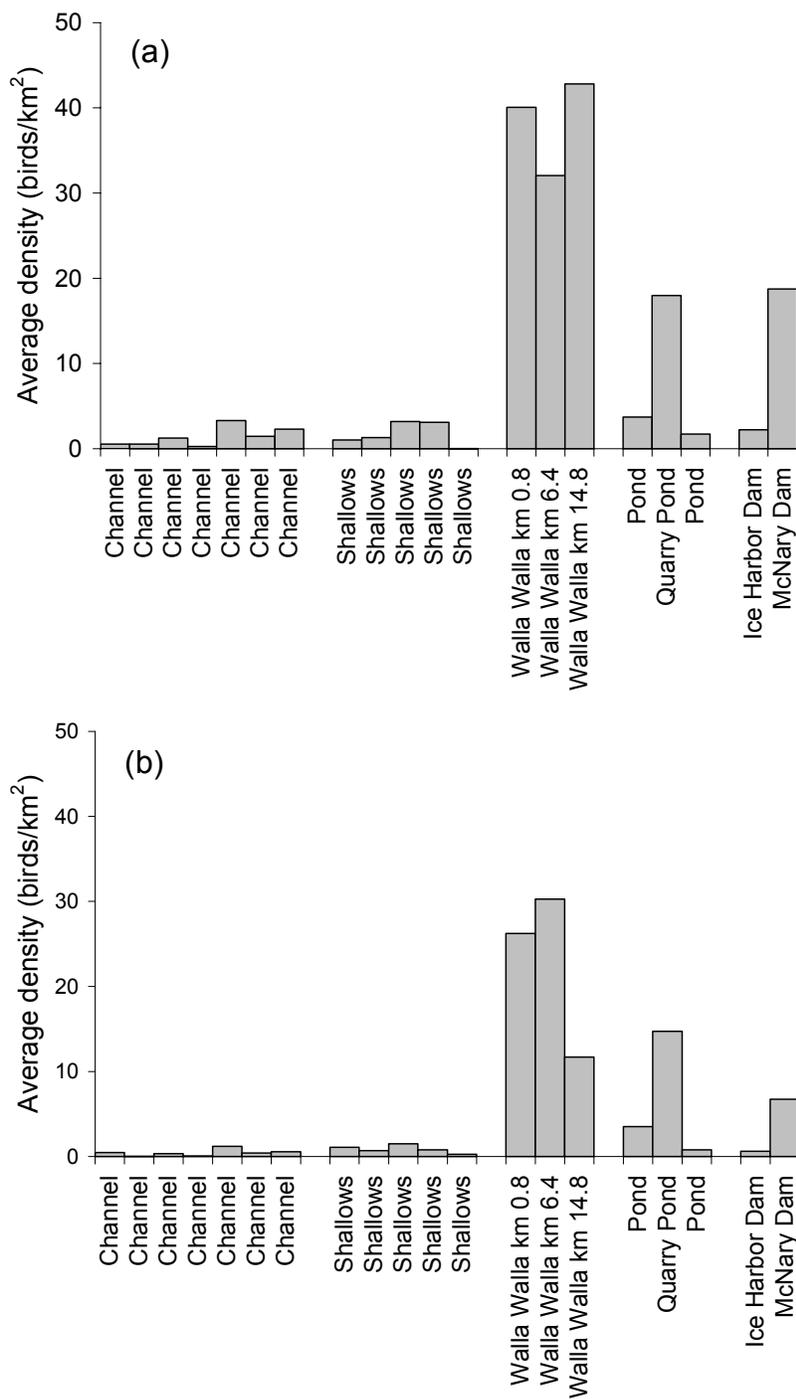


Figure 4.6. Densities of foraging Caspian terns at each of 20 sites near Crescent Island surveyed during the breeding season in 2000 (a) and 2001 (b).

these estimates and average densities of foraging terns at sampled sites, we estimated by extrapolation the proportion of terns that used each habitat type during the breeding season. In 2000, 60% of foraging by terns was estimated to have occurred in mainstem habitat, 11% on the Walla Walla River, 12% in ponds, and 17% near hydroelectric dams; in 2001, 49% of foraging terns used mainstem habitat, 18% the Walla Walla River, 21% ponds, and 12% the vicinity of hydroelectric dams (Figure 4.7). Thus despite the high densities of foraging terns observed on the Walla Walla River, the estimated proportion of foraging terns that used this habitat type was less than 20%.

There were significant differences in the numbers of foraging terns observed across all sites according to time of day in both 2000 ($\chi^2_2 = 13.2688$, $P = 0.0013$) and 2001 ($\chi^2_2 = 9.5146$, $P = 0.0086$); however, circadian patterns of foraging behavior differed between years. In 2000, more foraging terns were observed in the evening (3.35 ± 0.45 terns/10-minute observation period), compared to mid-day (2.09 ± 0.27 terns/observation period), and morning (1.65 ± 0.25 terns/observation period), while in 2001 more foraging terns were observed in the morning (1.24 ± 0.25 terns/observation period), compared to mid-day (0.80 ± 0.13 terns/observation period), and evening (1.05 ± 0.14 terns/observation period). There were no differences in the number of foraging terns observed when it was clear versus when it was cloudy in either 2000 ($Z = -0.1715$, $P = 0.86$) or 2001 ($Z = -0.9314$, $P = 0.35$). Wind speed was associated with differences in the number of foraging terns observed in 2001 ($Z = 2.4265$, $P = 0.015$); more foraging terns were observed during calm conditions (1.10 ± 0.14 terns/observation period) than when it was windy (0.72 ± 0.12 terns/observation period). There was no difference, however, in the number of foraging terns observed with respect to wind speed in 2000 ($Z = -1.4204$, $P = 0.16$).

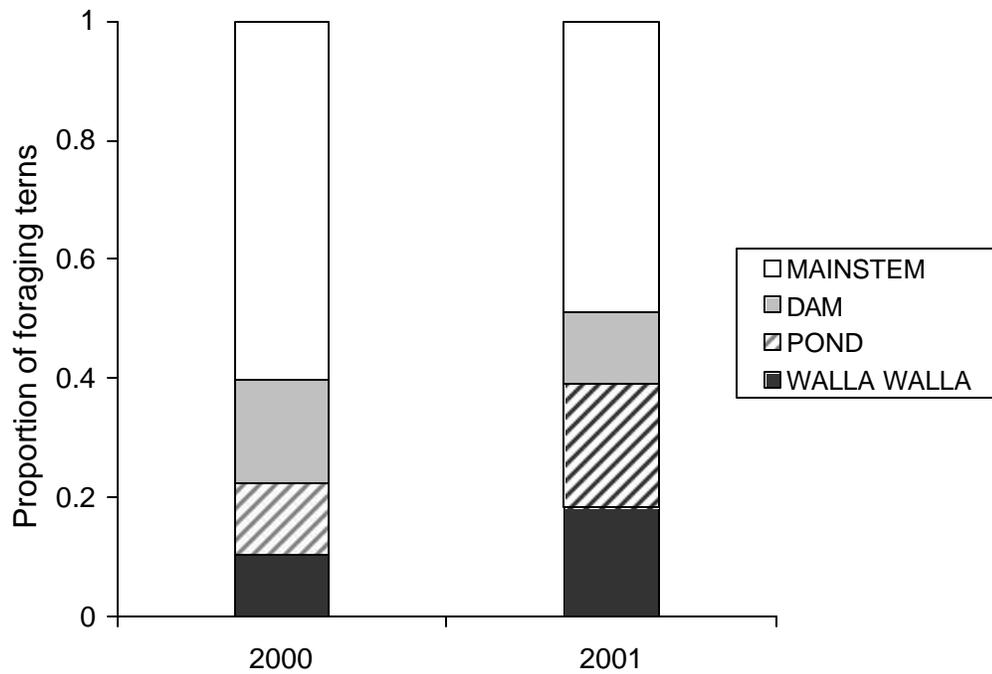


Figure 4.7. Estimated proportion of foraging terns that used four habitat types near Crescent Island, 2000-2001.

DISCUSSION

The primary objective of this study was to quantify predation on juvenile salmonids by Caspian terns nesting at Crescent Island, and a secondary objective was to better understand the foraging ecology of terns using this colony. In order to interpret the results presented here, we will attempt to (1) assess potential biases in the determination of forage fish consumption estimates for Crescent Island Caspian terns, (2) compare the magnitude of predation on juvenile salmonids by Caspian terns nesting at Crescent Island to that of other piscivores in the Columbia River basin, (3) examine how these predation impacts may differ based on where in the river system the predation is occurring, (4) investigate predation rates by Caspian terns at Crescent Island, and how these rates may differ based on species of salmonids and flow regimes, and (5) assess if prey aggregations may account for high densities of foraging terns, thereby affecting the way in which tern predation is directed at juvenile salmonids near Crescent Island. The results of this study will be used to consider whether management of Caspian terns nesting on Crescent Island is warranted and, if so, which management strategy is best. Thus consideration of all relevant factors is critical.

While the estimates presented here of salmonid consumption by Caspian terns nesting at Crescent Island will provide resource managers with information on the magnitude of tern predation at this site, there are potential biases in the bioenergetics model that may influence the accuracy of these estimates. One major uncertainty in our estimates is the effect of kleptoparasitism by gulls on tern consumption of juvenile salmonids; California gulls nesting at Crescent Island frequently pirated Caspian tern bill loads (see Chapter 2). In order to compensate for this kleptoparasitism, Caspian terns nesting at Crescent Island may take more juvenile salmonids than is necessary to meet their own energetic requirements and those of their young. Because we used bioenergetics modeling,

our estimates of salmonid consumption are based on the energy requirements of terns, and thus do not compensate for prey caught by terns that are subsequently pirated by gulls. This uncertainty may result in an underestimation of total predation on salmonids by Caspian terns. Gull kleptoparasitism rates recorded at the Crescent Island tern colony were 21.5% in 2000 and 16.7% in 2001 (see Chapter 2), suggesting that estimates of smolt losses to terns based on the bioenergetics model may have been somewhat low.

In addition, there was uncertainty associated with some of the inputs to the bioenergetics model. We used measurements of daily energy expenditure obtained from Caspian terns breeding in the Columbia River estuary to estimate energy expenditure rates of terns nesting at Crescent Island. Mean temperatures during the breeding season are approximately 5°C higher at Crescent Island than at Rice Island (TWC 2002), a factor that may influence DEE. While Tinbergen and Dietz (1994) found a negative relationship between DEE and temperature in great tits, it has been suggested that climate does not greatly affect DEE in larids (Golet et al. 2000). If there is a negative relationship between DEE and temperature in Caspian terns (within this range of ambient temperatures), our estimates of salmonid consumption by terns nesting at Crescent Island would be overestimated.

We were also unable to evaluate the accuracy of our estimates of average mass of non-salmonid prey items. While we assessed our ability to estimate length of salmonid prey with whole fish collected in the Columbia River estuary, we were not able to do this with non-salmonid prey types. Because of differences in shape and size of these prey items, the accuracy of our length estimates may have differed among types of non-salmonid prey. The length-mass regressions, on the other hand, were likely good predictors of the mass of prey, once length was determined, as demonstrated by the generally high R^2 values for these equations (Table 4.2).

Despite the potential inaccuracies mentioned above, estimates of colony size and the seasonal attendance patterns of adult terns on Crescent Island were likely quite accurate, because of the relatively small size of this tern colony. A comparison of the total number of terns counted from an observation blind and from aerial photography of Crescent Island differed by 1% or less in 2000 and 2001 (M. Antolos, unpubl. data). Because the number of tern breeding pairs may be a large contributor to the uncertainty in estimating salmonid consumption by a Caspian tern colony (Roby et al. 2003), our confidence in these estimates at Crescent Island is significant.

While we were not able to eliminate all sources of bias in our estimates of salmonid consumption by Caspian terns nesting at Crescent Island, these estimates provide useful brackets for the magnitude of predation on juvenile salmonids by terns breeding at this colony. These data represent the best available information on salmonid predation by terns at this site and thus will be important in guiding decisions regarding tern management at Crescent Island. In order to place this level of predation in perspective, comparisons to other piscivores in the Columbia River basin are useful.

Caspian terns nesting at Crescent Island consumed far fewer salmonids during the study period than Caspian terns nesting at Rice Island in the Columbia River estuary in either 1997 or 1998, when terns consumed an estimated 8.1 million and 12.4 million smolts, respectively (Roby et al. 2003). Total consumption of juvenile salmonids by Caspian terns nesting at Crescent Island was less than one-tenth that at Rice Island, mainly because of the much smaller colony size at Crescent Island. Smolt consumption estimates at Rice Island led to active management of Caspian terns nesting at this site in 1999 in order to reduce impacts to ESA-listed salmon ESUs (Roby et al. 2002).

Active management of Caspian terns in the Columbia River estuary involved relocating terns nesting at Rice Island to an historic breeding site on East

Sand Island, 26 km down-river, where terns were expected to consume fewer salmonids (Roby et al. 2002). Caspian terns nesting at the managed colony site on East Sand Island consumed about 50% fewer juvenile salmonids in 2001 (ca. 6 million; D.E. Lyons, D.D. Roby, K. Collis, unpubl. data) than did the former colony on Rice Island. Nevertheless, consumption of juvenile salmonids by terns nesting on East Sand Island in 2001 was still about an order of magnitude greater than that of terns nesting on Crescent Island. Despite the continued impact of the East Sand Island tern colony on smolt survival, a decision has not yet been made to reduce the size of this managed colony to further improve smolt survival through the Columbia River estuary. Thus losses of juvenile salmonids to predation by terns nesting on Crescent Island was about one-tenth that of terns nesting in the Columbia River estuary, both before and after management action was implemented to reduce tern predation on out-migrating smolts.

Predation on juvenile salmonids by Caspian terns nesting at Crescent Island was also lower than that estimated for northern pikeminnow in John Day Reservoir, on the mainstem Columbia River, downstream from Crescent Island. Rieman et al. (1991) reported that northern pikeminnow in this reservoir consumed approximately 2.1 million juvenile salmonids annually, while terns at Crescent Island consumed less than one million juvenile salmonids in 2000 and 2001. Beamesderfer et al. (1996) estimated that northern pikeminnow consumed a total of 16 million juvenile salmonids in the lower Columbia and Snake rivers annually, more salmonids than the highest consumption estimates derived for Caspian terns nesting at Rice Island and Crescent Island combined (12.4 million at Rice Island in 1998 and 679,000 at Crescent Island in 2001). These consumption estimates have led to the active management of northern pikeminnow to reduce predation rates on juvenile salmonids (Friesen and Ward 1999).

Gulls foraging below Wanapum Dam on the mid-Columbia River consumed fewer juvenile salmonids (approximately 112,000 to 119,000 smolts in 1982; Ruggerone 1986) than Caspian terns nesting at Crescent Island in 2000 or 2001. Gulls and terns are currently culled at mid-Columbia River dams in order to reduce predation on threatened and endangered stocks of juvenile salmonids, a decision that was prompted in large part by the Ruggerone (1986) study (Pochop et al. 1998). Gull predation rates on juvenile salmonids at Wanapum Dam presented by Ruggerone (2%; 1986) also prompted the elimination of a ring-billed gull colony on Cabin Island, WA (Pochop et al. 1998). Thus in this instance, piscivorous bird control was implemented despite a relatively low predation rate. Consumption rates of juvenile salmonids by gulls at Wanapum Dam was likely much lower than salmonid consumption by Caspian terns nesting at Crescent Island because there were many fewer gulls foraging at the dam (250-350 gulls; Ruggerone 1986) than there were terns nesting at Crescent Island (approximately 1,200 at the peak of the breeding season). In addition, the above study focused on a single foraging area, the tailrace of Wanapum Dam, while additional salmonids may have been consumed by gulls at other foraging locations throughout the region (e.g., Priest Rapids Dam, Rock Island Dam).

In addition to comparing the magnitude of predation among piscivores in the Columbia River basin, it is also important to compare the impacts of various predators on prey populations. For instance, predators may differ in the proportion of species of salmonids consumed, the proportion of hatchery or wild salmonids consumed, the number of individuals from ESA-listed stocks consumed, or the nature of the mortality (additive vs. compensatory). Juvenile salmonids migrating past Crescent Island are approximately 500 km from the Pacific Ocean. Thus tern mortality at this stage may be largely compensatory; many of the smolts consumed may have otherwise experienced mortality during their migration to the sea. Sources of mortality may include, but are not limited

to: direct and indirect mortality caused by dams, predation by fish, thermal stress, disease, or physiological stress from traversing slackwater impoundments. Therefore, tern predation at this up-river site may have less of an effect on the number of adult salmonid returns than equivalent tern predation in the Columbia River estuary.

In addition to examining the nature of salmonid mortality caused by Caspian terns, it is important to consider the species, rearing histories, and ESA-listing status of salmonids consumed by piscivores in the Columbia River basin. In this study, we estimated numbers of steelhead consumed, as well as total salmonid consumption, by Caspian terns nesting at Crescent Island. We were not, however, able to make further species distinctions, nor could we estimate the proportion of hatchery vs. wild smolts consumed. Perhaps most importantly, we were not able to estimate the number of ESA-listed salmonids consumed or determine the proportion of particular salmonid ESUs consumed by Crescent Island terns. Such additional insights regarding tern predation rates on ESA-listed stocks would greatly aid in informing future management decisions at Crescent Island.

One way to improve comparison of predation impacts on juvenile salmonids in the Columbia River basin is to convert consumption estimates into predation rates (the proportion of salmonids consumed in relation to total numbers available). We were not able to do so directly at Crescent Island because total numbers of juvenile salmonids migrating past Crescent Island were not available. However, we examined data on passive integrated transponders (PIT tags) from juvenile salmonids that were detected on the Crescent Island tern colony by NOAA Fisheries (Ryan et al. 2001, Glabek et al. 2003) to gain insight into predation rates at Crescent Island. PIT tags are used basin-wide in various studies of juvenile salmonids and these internal tags are consumed by Caspian terns when foraging on tagged salmonids and then deposited on their breeding colonies

(Collis et al. 2001). At Crescent Island, NOAA Fisheries detected a total of 3,363 smolt PIT tags from the 2000 migration year and 13,258 smolt PIT tags from the 2001 migration year on the tern colony (Ryan et al. 2001, Glabek et al. 2003). The proportion of PIT-tagged salmonids detected at Lower Monumental Dam on the lower Snake River and then later detected on the Crescent Island tern colony was determined by NOAA Fisheries during 1998-2001.

Total predation rates based on this proportion ranged between 0.4% and 13.0%, depending on migration year and salmonid species (Glabek et al. 2003). Estimated tern predation rates on steelhead were higher than on spring/summer (yearling) chinook. In 2000 and 2001, 1.7% and 13.0%, respectively, of PIT-tagged steelhead detected at Lower Monumental Dam were later detected on the Crescent Island tern colony; this compares to 0.4% and 4.1% of PIT-tagged spring/summer chinook detected at the dam and later detected on the tern colony (Glabek et al. 2003). Thus tern predation rates may have been 3-4 times higher on steelhead than on spring/summer chinook, based on PIT tag detections. While the proportion of steelhead in the diet of Caspian terns nesting at Crescent Island was less than 15% on average (see Figure 4.4), in 2001, the proportion of steelhead in the diet reached a peak of 40% during 28 May-10 June (Figure 4.4). Estimated passage of juvenile steelhead through McNary Dam was also characterized by a large peak in late May of 2001, but one to two weeks earlier during 20-27 May (FPC 2003). This suggests that in 2001, Caspian terns may have foraged primarily on steelhead that lingered in McNary reservoir, after peak passage occurred. This supports our hypothesis that predation on juvenile salmonids by Crescent Island Caspian terns is largely compensatory; smolts that do not travel quickly through the hydrosystem may have less of a chance of survival, irrespective of predation by terns, than those that migrate quickly and synchronously with peak passage.

Based on PIT tag detections at Crescent Island, Caspian tern predation rates on both salmonid species were more than 7 times higher in 2001 compared to 2000. This difference is likely due, at least in part, to severe drought conditions in the Columbia River basin during the spring/summer of 2001. Total flow through the Columbia River in 2001 was much lower than river flows in 2000, as well as the 10-year average; in addition, smolt travel times were longer in 2001 than in 2000 (FPC 2002). These conditions created lower-than-average survival of both steelhead and chinook salmon smolts through the Columbia and Snake rivers in 2001 (FPC 2002). Because juvenile salmonids spent more time migrating through the river in 2001, they were likely more vulnerable to tern predation than in other years. Thus high tern predation rates in 2001 reflected high juvenile salmonid mortality rates in general. This lends additional support to our hypothesis that mortality of juvenile salmonids caused by Caspian terns near Crescent Island may be largely compensatory; in 2001 when juvenile salmonids experienced high mortality in general, predation rates by Caspian terns were also higher. During non-drought years (1998-2000), Caspian tern predation rates were within the range of 0.4-4.1% (Glabek et al. 2003). Thus it may be that Caspian tern predation rates are within this range during “typical” years, and increase to predation rates seen in 2001 only when drought conditions prevail. Apparently, river conditions can have a large effect on Caspian tern predation rates on juvenile salmonids at Crescent Island, and should be considered when management decisions are being evaluated for this colony.

Large proportions of juvenile salmonids from the Snake River basin are transported each year by barge and truck and released below Bonneville Dam by the U.S. Army Corps of Engineers in order to improve smolt survival through the hydrosystem (NMFS 2000). In 2001, an estimated 98% of spring/summer chinook and 99% of steelhead originating in the Snake River basin (reaching Lower Granite Dam) were transported past Crescent Island and released below

Bonneville Dam; in 2000, an estimated 71% of spring/summer chinook and 81% of steelhead were transported (FPC 2002). Therefore, only a small proportion of all smolts produced in the Snake River basin are left in-river where they may become vulnerable to predation from terns nesting on Crescent Island. While Caspian tern predation rates on Snake River steelhead in 2001 were high (13.0%; Glabek et al. 2003), this level of predation was experienced by only about 1% of all steelhead smolts from the Snake River basin.

This study also investigated the foraging ecology of Caspian terns nesting at Crescent Island, in order to provide additional information that may be useful in forming decisions regarding tern management at this site. Our results indicate that terns concentrated their foraging effort along the Walla Walla River, at certain ponds near the Columbia River, and near McNary Dam compared to the deep river channels or shallows of the mainstem Columbia and Snake rivers. Terns may experience greater foraging success at these sites, although this was not measured directly. Distance from the Crescent Island colony to foraging sites was negatively associated with densities of foraging terns in 2001, but not in 2000, demonstrating that in 2000, certain distant foraging sites tended to be used as much as near sites. This result is not surprising given observations of Caspian terns nesting in Potholes Reservoir, WA; at this colony terns regularly commuted over 50 km to forage on salmonids at mid-Columbia River dams, despite the potentially higher energetic costs incurred by adults commuting to distant sites (see Chapter 2).

The highest densities of foraging terns were observed along the Walla Walla River, suggesting that prey may be more available in this small tributary of the Columbia River. Wild salmonids have been absent from the Walla Walla River basin since the 1920's, with the exception of summer steelhead (CTUIR 1989); however, terns foraging on the Walla Walla River may be targeting juvenile salmonids of hatchery origin. Hatchery releases in the Walla Walla

Basin exceeded 200,000 juvenile summer steelhead during late April of 2000 and 2001 (FPC 2003), which may provide a significant food source for Caspian terns nesting at Crescent Island early in the breeding season. A similar scenario occurred in Commencement Bay, WA, where Caspian terns were suspected of focusing their foraging effort on hatchery-raised juvenile salmonids from the Puyallup River (Thompson et al. 2002). While hatchery releases of smolts on the Walla Walla River may provide numerous easily-captured prey for Caspian terns, this small tributary of the Columbia River does not provide a large area of foraging habitat (ca. 1.0 km² within the study area) compared to mainstem habitat on the Columbia and Snake rivers (145 km²). We estimated that less than 20% of foraging by terns from the Crescent Island colony occurred on the Walla Walla River.

Cloud cover and wind speed had little effect on numbers of foraging Caspian terns counted on the survey route, although Caspian terns may prefer to forage when it is calm. Our results demonstrated that circadian patterns of foraging by Caspian terns differed between years. This may be related to temporal differences in prey availability between years, due to differences in river flow or vertical distribution of prey in the water column; however, we have no evidence that this was a causal factor. These results suggest that time of day may have a variable effect on Caspian tern foraging patterns, and that weather conditions do not have a marked effect on Caspian tern foraging behavior.

The results of this study can help resource managers decide whether management of Caspian terns is warranted at Crescent Island. Management of predators on juvenile salmonids in the Columbia River basin has been initiated based on estimates of salmonid consumption that both exceeded and were below the magnitude of predation estimated for terns nesting on Crescent Island. Therefore it is possible that resource managers will take management action to reduce losses of juvenile salmonids to Crescent Island terns; our analysis of

salmonid consumption, foraging distribution, and habitat use by Caspian terns nesting at Crescent Island suggests several potential management strategies: (1) increase spill at dams to decrease smolt travel times through the hydrosystem, (2) install bird wires and other bird deterrents at McNary Dam, (3) stock local ponds with forage fish that are not ESA-listed, (4) time releases of hatchery steelhead on the Walla Walla River so that they occur before Caspian terns begin breeding activities, and (5) relocate terns to a new nesting site where access to juvenile salmonids is reduced.

In the Columbia River estuary, Caspian terns were managed by relocating the breeding colony to a site where less predation on juvenile salmonids was expected; thus it is possible that resource managers will consider actively reducing numbers of Caspian terns nesting on Crescent Island, based on estimates of salmonid consumption by Caspian terns reported here and by Glabek et al. (2003). There are a number of factors to consider when making this decision, however, which were not addressed in this study. Caspian terns nesting on another island in the mid-Columbia River (Three Mile Canyon Island) consumed as high or higher a proportion of juvenile salmonids in the diet (86% in 2000; see Chapter 2) as terns nesting at Crescent Island, suggesting that relocating Caspian terns to alternative colony sites in the mid-Columbia River will not reduce smolt mortality. In addition, Caspian terns may commute long distances to forage on salmonids (over 50 km from the Solstice Island colony in Potholes Reservoir to mid-Columbia River dams; see Chapter 2). Although relocating the Crescent Island tern colony to an alternative site off the Columbia and Snake rivers may reduce their reliance on juvenile salmonids as a food source, finding a suitable site in the region where juvenile salmonids would not be in the diet might be problematic. In addition, Caspian terns are federally protected under the Migratory Bird Treaty Act of 1918, and management of Caspian terns nesting in the Columbia River estuary has been challenged in court by bird conservation

groups (NAS v. Butler). Therefore, any management action directed toward reducing tern predation on juvenile salmonids at Crescent Island will require natural resource managers, and perhaps the courts, to balance the competing interests of protected birds with threatened and endangered species of salmonids.

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Chapter 5

SUMMARY AND SYNOPSIS

Michelle Antolos

The research presented here on the breeding and foraging ecology of Caspian terns (*Sterna caspia*) in the mid-Columbia River and elsewhere in the Columbia Plateau region addressed three main objectives: (1) to investigate the number and size of Caspian tern colonies on the Columbia Plateau, and their relative dependence on juvenile salmonids as a food source compared to colonies in the Columbia River estuary; (2) to evaluate the nature of the trade-off between nesting density and breeding success of Caspian terns in order to provide guidelines for minimum area requirements for terns nesting at managed colony sites; and (3) to estimate the number of juvenile salmonids consumed by Caspian terns nesting at the largest colony on the Columbia Plateau, and to identify factors that favor predation on out-migrating juvenile salmonids by Caspian terns in the mid-Columbia River.

Caspian tern colony size on the Columbia Plateau ranged from tens of breeding pairs to nearly 700 pairs. All Caspian tern colonies in the study area were associated with larger gull colonies, which may have limited tern colony area. Mink predation caused complete abandonment of a tern colony of 275 pairs in 2000, which was not re-colonized in 2001. A new colony site was discovered on an island in Potholes Reservoir, where Caspian terns commuted over 50 km to the Columbia River to forage on juvenile salmonids. At colonies on the mid-Columbia River, the majority of Caspian tern prey items consisted of juvenile salmonids. High nesting densities at mid-Columbia River colonies suggested that availability of breeding habitat may have limited colony size. Fledging success varied dramatically and was lowest at colonies where nest predation was a factor.

While Caspian tern colonies are highly dynamic within the study area, there was no evidence that management of Caspian terns in the Columbia River estuary caused emigration of terns to up-river colonies. The size and number of Caspian tern colonies on the Columbia Plateau region were likely constrained by the availability of suitable nesting habitat near abundant prey, a resource that

appears limited within the study area. While Caspian terns nesting at colonies on the mid-Columbia River rely more on juvenile salmonids as a food source than terns nesting at East Sand Island in the Columbia River estuary, the stability and small size of the Columbia Plateau sub-population will likely keep the magnitude of tern predation on juvenile salmonids in this region well below that currently observed in the Columbia River estuary.

The largest Caspian tern colony in the study area, on Crescent Island, consisted of 688 breeding pairs in 2001. The range of nest densities was 0.25-1.48 nests/m². Productivity did not differ between high- and low-density nests at this colony, and was strongly and negatively related to nest initiation date. Early nests were more productive, were in areas of higher nest density, and were further from the colony edge than late nests; the breeders at these nests may have been older and more experienced. Conversely, the strong effect of timing may have been attributable to seasonal declines in prey resources. These results suggest that nesting at high densities does not incur immediate reproductive costs to Caspian terns, despite the increased potential for encounters with aggressive conspecifics. This information may be helpful for resource managers deciding minimum area requirements for breeding Caspian terns at managed colony sites (e.g., at East Sand Island; Roby et al. 2002). These data suggest that if colony area requirements are planned so that nest densities are maintained within the range observed at Crescent Island, density alone is not likely to affect the reproductive success of Caspian terns.

I estimated that Caspian terns breeding at Crescent Island consumed 382,000-547,000 juvenile salmonids during the 2000 breeding season, and 533,000-825,000 juvenile salmonids during the 2001 breeding season. Densities of foraging terns were higher on the Walla Walla River, at certain ponds, and near McNary Dam, compared to deep river channel or shallows on the Columbia and Snake rivers. The highest densities of foraging terns were observed on the Walla

Walla River; however, the proportion of foraging terns predicted to use this habitat type was less than 20%. Total salmonid predation by Crescent Island Caspian terns was less than that reported for other predators in the Columbia River (i.e., Caspian terns nesting in the Columbia River estuary or northern pikeminnow in the John Day Reservoir), but more than that reported for gulls foraging at Wanapum dam. These predators have been managed to reduce predation rates on juvenile salmonids, so comparisons to the Crescent Island colony are relevant.

The results of this study can help state, federal, and tribal resource managers decide whether management of Caspian terns is warranted at Crescent Island. There are a number of factors to consider when making this decision, however, which were not addressed in this study. Management of predators on juvenile salmonids in the Columbia River basin has been initiated based on estimates of salmonid consumption that both exceeded and were below the magnitude of predation estimated for terns nesting on Crescent Island. Therefore, it is likely that resource managers will consider actively reducing numbers of Caspian terns nesting on Crescent Island, based on estimates of salmonid consumption by Caspian terns reported here. Relocating nesting Caspian terns to alternative colony sites in the mid-Columbia River may not reduce smolt mortality, given that Caspian terns nesting on Three Mile Canyon Island in the mid-Columbia River consumed as high or higher a proportion of juvenile salmonids in the diet than those nesting at Crescent Island. In addition, the propensity of Caspian terns to commute long distances to forage on salmonids (over 50 km from the Solstice Island colony in Potholes Reservoir to hydroelectric dams in the mid-Columbia River) complicates finding a suitable site to relocate the colony. Although culling gulls and terns at mid-Columbia River dams to enhance smolt survival is on-going, management of Caspian terns nesting in the Columbia River estuary has been successfully challenged in court by bird

conservation groups (*NAS v. Butler*). Because Caspian terns are federally protected under the Migratory Bird Treaty Act of 1918, any management action directed toward reducing tern predation on juvenile salmonids will require natural resource managers, and perhaps the courts, to balance the competing interests of protected birds with threatened and endangered species of salmonids.

Because of these competing interests, I recommend that resource managers conduct a comprehensive examination of the ecological, social, and political aspects of this issue before the data presented here are used to justify decisions regarding Caspian tern management at Crescent Island. This analysis could be conducted by developing an ecological risk assessment model whereby the risks and benefits associated with potential management strategies are outlined for Caspian terns at Crescent Island. Risk assessment is a frequently used tool in human health issues, and a particular type of risk assessment, ecological risk assessment, has become one of the dominant decision-making tools in current environmental policy (Suter 1993, Lackey 1996). Ecological risk assessment provides a quantitative basis for comparing and prioritizing risks, acknowledges the inherent uncertainty in predicting future environmental states, and separates the scientific process of estimating the magnitude and probability of effects from the process of choosing among alternatives (Suter 1993).

Because of these characteristics, ecological risk assessment would be a good candidate for evaluating the ecological, social, and political aspects of Caspian tern management in the mid-Columbia River. It would allow decision-makers to examine various management options, to assign risks according to a variety of criteria, and evaluate uncertainties associated with each management strategy. In this way, for a given management strategy resource managers could (1) evaluate the likelihood that Caspian tern predation rates on juvenile salmonids would be reduced, (2) integrate concerns for financial costs and public opinion, (3) assess the probability that a management action would prompt litigation from

either bird or salmon conservation groups, and (4) estimate the uncertainty associated with each of these outcomes given a particular management strategy. While developing a risk assessment model will not provide an answer to the question of whether to manage terns at Crescent Island, the process of developing an *explicit* assessment of the risks and benefits of management strategies will likely aid in the development of an informed management plan for Caspian terns nesting in the mid-Columbia River.

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