

## **Appendix C.**

# **Caspian Tern Predation on Juvenile Salmonid Outmigrants in the Columbia River Estuary**

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## EXECUTIVE SUMMARY

- Relatively new human-constructed islands in the Columbia River estuary have provided breeding habitat for Caspian terns, where they have been able to successfully exploit juvenile salmonids as a food resource.
- The effect of Caspian tern predation: varies between years, varies among salmonid species, is greatest on steelhead, and is lowest on wild yearling chinook.
- Caspian tern predation on juvenile salmonids reduces salmon population growth rate and thus recovery, however, removing all tern predation will not-- by itself--lead to full recovery of any listed salmon and steelhead stock.
- The effect of Caspian tern predation on recovery may be comparable to fish passage improvements at Columbia River dams and harvest reductions for some Evolutionarily Significant Units.
- Relocating Caspian terns to habitat closer to the mouth of the Columbia River significantly reduced predation impact on juvenile salmon.
- Additional PIT tag data needs to be collected and evaluated to validate initial predation rates at East Sand Island.

## BACKGROUND

The ecosystems inhabited by anadromous salmonids are extensive and complex. In the case of upper Columbia River and Snake River salmon and steelhead, their range extends inland as far as 1500 km and rise to elevations of 2500 m above mean sea level. Their oceanic range extends through the North Pacific Ocean to the Bering Sea and the Sea of Japan. Climate conditions and human activities have had adverse affects on water flows, river conditions, spawning and rearing habitat, ocean productivity, and eventually, salmonid survival and productivity. Wild and naturally reproducing stocks of steelhead have declined dramatically in the interior Columbia River Basin (McClure *et al.* 2003). Wild and naturally reproducing spring- and summer-run chinook stocks also have declined dramatically throughout the Pacific Northwest. As a result, nearly every population of naturally producing anadromous salmonids in the Columbia River Basin is now listed (or is a candidate for listing) under the Endangered Species Act (ESA).

Salmonids experience high mortality rates as juveniles in freshwater, the estuary and early ocean, leading researchers to suggest that reducing mortality during the juvenile stage has the potential to increase population growth rates (Kareiva *et al.* 2000). Although significant mortality of juvenile salmonids occurs in the ocean, our ability to influence ocean survival is limited. Therefore, improvements in freshwater survival and production are imperative and can directly affect the number of returning adult salmonids (Raymond 1988, Beamesderfer *et al.* 1996).

Many of the measures taken to restore anadromous salmonid production in the Columbia River Basin have focused on improving the survival of juvenile migrants through the mainstem dams. Various life-cycle models indicate that mortality of juveniles during migration in freshwater constrains anadromous salmonid production in the Columbia River Basin, thereby reducing the benefits of enhancement measures upstream (Beamesderfer *et al.* 1996, Kareiva *et al.* 2000). Increasing populations of piscivorous birds (primarily Caspian terns) nesting on islands in the Columbia River estuary annually consume large numbers of migrating juvenile salmonids (Roby

*et al.* 1998) and thus constitute one of the factors that currently limit salmonid stock recovery (Roby *et al.* 1998; Independent Multidisciplinary Science Team 1998; Johnson *et al.* 1999). Therefore, reducing Caspian tern predation in the estuary, is one potential mechanism to reduce mortality, thereby increasing population growth rates of Endangered Species Act (ESA) listed salmonid Evolutionarily Significant Units (ESUs)<sup>1</sup> in the Columbia River Basin.

Anthropogenic changes in the Columbia River Basin appear to have facilitated increases in populations of colonial waterbirds. The largest recorded colony of Caspian terns in the world now occupies East Sand Island—a natural island that has been augmented by depositing upon it dredge material from maintaining a navigation channel in the Columbia River estuary (Roby *et al.* 1998). There, the terns feed on large numbers of migrating juvenile salmon and steelhead, and basin-wide losses to avian predators now constitute a substantial proportion of individual salmonid runs (Roby *et al.* 1998).

In the early 1990s, National Marine Fisheries Service (NOAA Fisheries) staff at the Point Adams Field Station noted substantial increases in the size of newly established Caspian tern nesting colonies on Rice Island in the Columbia River estuary. Several estuary islands on which piscivorous birds nest (Fig. 1) were created from or augmented by materials dredged to maintain the Columbia River Federal Navigation Channel. Before 1984, there were no recorded observations of terns nesting in the Columbia River estuary, when approximately 1000 pairs apparently moved from Willapa Bay to nest on newly deposited dredge material on East Sand Island. In 1986, those birds moved to Rice Island, an island created by the Army Corps of Engineers for the purpose of dredge disposal. The Caspian tern colonies in the estuary have since expanded to 9,000-10,000 pairs, the largest ever reported. In 1999, the colony was encouraged to relocate to East Sand Island. In 2001, the majority of the West Coast population nested on just four acres on East Sand Island; in 2002, the terns nested on six acres.

Because of the growing concern over the increasing impacts of avian predation on salmonid smolts, NOAA Fisheries required the Bonneville Power Administration (BPA) and U.S. Army Corps of Engineers (USACE) to study avian predation in the Columbia River estuary and, if necessary, develop potential measures for managing the predator populations. These requirements were part of the 1995 Formal Consultation on the Operation of the Federal Columbia River Power System and Juvenile Transport Program (NMFS 1995). Oregon State University (OSU) and the Columbia River Inter-Tribal Fish Commission (CRITFC) began the research in 1996. The losses of salmonid smolts to newly established and expanding numbers of avian predators is of concern as currently 12 ESUs of anadromous salmonids native to the Columbia River Basin are listed as threatened or endangered under the ESA (Fig. 2).

As avian predation on salmonids is a multi-jurisdictional issue, NOAA Fisheries, the U. S. Army Corps of Engineers, U.S. Fish and Wildlife Service, the Bonneville Power Administration, the

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<sup>1</sup> Under the Endangered Species Act, the National Marine Fisheries Service (NOAA Fisheries) lists species, subspecies and distinct population segments of vertebrates. NOAA Fisheries policy stipulates that a salmon population will be considered distinct if it represents an “evolutionary significant unit” (ESU) of the biological species (Waples 1991). For the purposes of conservation under the ESA, an Evolutionarily Significant Unit (ESU) is a distinct population segment that is substantially reproductively isolated from other conspecific population units and represents an important component in the evolutionary legacy of the species (Waples 1991).

Columbia River Inter-Tribal Fish Commission, and resource agencies of the states of Washington, Idaho and Oregon formed the Caspian Tern Working Group (CTWG) to develop a long-term management plan for reducing tern predation in the estuary. As part of this effort, NOAA Fisheries is evaluating the overall risk that tern predation presents to listed salmonid populations.

The intent of this document is to summarize what is known about Caspian tern predation impacts to salmonids in the Columbia River estuary. We have included a summary of Caspian tern populations in the Columbia River basin and estimates of predation rates gained from recovery of PIT tags and bioenergetics modeling. We have also included analyses of predation impacts on ESA-listed steelhead through the use of a life-cycle model that focuses on Caspian terns nesting on East Sand Island since their relocation from Rice Island. This information will be useful to resource managers to develop management options to reduce predation impacts.

### **CASPIAN TERNS (*Sterna caspia*)**

Caspian terns are highly migratory and are nearly cosmopolitan in distribution (Harrison 1983; Harrison 1984). In North America, nesting has been reported on the west coast from Baja, California to the Bering Sea, in the interior from the Gulf Coast of Texas to Lake Athabasca, Saskatchewan, and on the east coast from the Florida panhandle to Labrador. Outside of North America, nesting has been reported in Australia, New Zealand, South Africa, Asia, and Europe.

Caspian Terns winter primarily on the Pacific coast from southern California south through west Mexico and Central America (Shuford and Craig 2002). Early estimates of the Pacific Northwest population were as many as 500 pairs nesting with gulls and cormorants as far north as Klamath Lakes in Oregon (Harrison 1984). Nesting colonies were first discovered in Washington near Moses Lake and Pasco in the 1930s, but coastal colonies were not recorded until the late 1950s, when one was found in Grays Harbor (Alcorn 1958, Penland 1976, 1981). Since the early 1960s, the population has shifted from small colonies in interior California and southern Oregon to large colonies nesting on human-created habitats along the coast (Gill and Mewaldt 1983). The current population in the Columbia River basin is part of a dramatic northward and coastward expansion in range and an overall increase in Caspian tern numbers in western North America.

The numbers of Caspian terns in western North America more than doubled between 1980 and 1999 (Cuthbert and Wires 1999). One reason for the increase is that human-created habitat provides high quality nest sites and is associated with population increases in many parts of North America (Cuthbert and Wires 1999). In the Columbia River estuary, Caspian terns have increased from a few scattered individuals before 1984 to nearly 10,000 pairs in 2002 (Fig. 3).

Caspian terns arrive in the Columbia River estuary in April and begin nesting at the end of the month (Roby *et al.* 1998). To avoid mammal and avian predators, terns construct their nests on islands (Harrison 1984) and show a preference for barren sand. They are piscivorous in nature (Harrison 1984), requiring about 220 grams (roughly one-third of their body weight) of fish per day during the nesting season. The timing of courtship, nesting and chick rearing corresponds with the outmigration of many of the salmonid stocks in the basin (Collis *et al.* 2002) (Fig. 4).

## ESTIMATING PREDATION IMPACTS

One approach to evaluating the extent of Caspian tern predation and resultant salmonid mortality uses bioenergetics modeling. Since 1997, biologists with the Bonneville Power Administration-funded research project ("Avian Predation on Juvenile Salmonids in the Lower Columbia River," - a joint project of Oregon State University, the U. S. Geological Survey, the Columbia River Inter-Tribal Fish Commission, and Real Time Research Consultants) have used observed salmonid consumption at tern colonies in a bioenergetics model (Roby *et al.* 1998) to estimate the consumption of salmonids in the Columbia River estuary.

This analytical approach indicates that salmon and steelhead constituted a major portion of tern diets, particularly when the birds nested on Rice Island. Diet analyses indicated that juvenile salmonids constituted 77.1% of prey items in 1997 and 72.7% of prey items in 1998 of Caspian terns nesting on Rice Island (Collis *et al.* 2002). During the peak of smolt out-migration of steelhead, yearling chinook salmon, and coho salmon through the estuary, when Caspian terns are in their incubation period in May, the diet of Caspian terns was consistently over 90% juvenile salmonids (Collis *et al.* 2002). This concentration on smolts as a food source translates into substantial juvenile mortality during the outmigration period.

Smolt consumption and the number of smolts estimated to reach the estuary from 1999 to 2002 is given in Table 1. The smolt consumption data is estimated from bioenergetics modeling, while the latter is estimated from data on fish passing through the hydropower system or transported around the system and released below Bonneville Dam. Smolt estimates are comprised only of steelhead, yearling chinook and hatchery coho, and should not be thought of as absolute totals. Estimates for subyearling chinook are not included, as their expansions are based on few data and thus not reliable, and they outmigrate later in the season and are subject to less predation pressure from terns. Estimates for chum are also not included as their outmigration is earlier in the season and they are thus subject to less predation pressure from terns.

Table 1. Estimates of outmigrating steelhead, yearling chinook and hatchery coho smolts reaching the estuary<sup>a</sup> and of juvenile salmonids consumed by Caspian terns in the Columbia River estuary 1999-2002.

Year	Number of smolts reaching estuary in millions	Number of smolts consumed in millions (95% C.I.)
1999	63.1	11.7 (9.4 - 14.0) <sup>b</sup>
2000	65.6	7.3 (6.1 - 8.6) <sup>b</sup>
2001	60.6	5.9 (4.8 - 7.0) <sup>b</sup>
2002	55.5	6.5 (5.5 - 7.6) <sup>c</sup>

<sup>a</sup> Data from NOAA Fisheries Fish Ecology Division, Sustainable Fisheries Division and Fish Passage Center. Includes estimated numbers of hatchery coho salmon only, no estimates are available for wild coho. Since no values for coho survival through the power system are available, estimates of survival of hatchery coho through the system were developed through the use of SIMPAS (NMFS 2000a) values for yearling chinook.

<sup>b</sup> Collis *et al.* 2001a

<sup>c</sup> Collis *et al.* 2002

Another approach uses detections of passive integrated transponders (PIT) tags on Caspian tern colonies to estimate salmonid predation rates overall as well as by ESU (Collis *et al.* 2001b, Ryan *et al.* 2001). In 1997 and 1998, 1 - 2 million ESA-listed salmonid smolts entered the Columbia River estuary, representing 1 - 2 % of all salmonid smolts migrating to the estuary. However, in 1999, seven additional ESUs of anadromous salmonids in the Columbia River Basin were listed, and roughly 6 million ESA-listed salmonid smolts entered the estuary along with over 80 million unlisted smolts, which were primarily of hatchery origin. The majority of juvenile salmonids in the estuary are of hatchery origin and the majority being consumed by Caspian terns are hatchery fish (Independent Multidisciplinary Science Team 1998). Overall, Caspian terns consumed approximately 10% to 19% of the estimated outmigrating population of juvenile salmonids originating from the Columbia River basin.

Since 1987, researchers in the Columbia River basin have placed over five million PIT tags in juvenile salmonids for a variety of studies (Ryan *et al.* 2001). Identifying PIT tags on bird colonies can provide a minimum estimate of proportion of the stocks that were consumed by terns in these colonies. In recent years, approximately one million juvenile salmonids have been PIT-tagged annually (Collis *et al.* 2001b), the vast majority of which are steelhead and chinook from the Snake River basin. Using PIT tag detection equipment, over 115,000 PIT tags were detected on Rice Island in 1998 and 1999 (Ryan *et al.* 2001). Collis *et al.* (2001b) indicate that the majority of these PIT tags detected were from steelhead and chinook, coho and sockeye salmon. Of the PIT tags placed in steelhead smolts in 1997 that were detected at Bonneville dam, 2.8% of wild smolts and 5.4% of hatchery-raised smolts were subsequently detected on the Rice Island tern colony (Collis *et al.* 2001b). For steelhead PIT-tagged in 1998 and detected at Bonneville Dam, 11.7% of wild smolts and 13.4% of hatchery-raised smolts were subsequently detected on the Rice Island tern colony (Collis *et al.* 2001b). For yearling chinook salmon PIT-tagged in 1998 and detected at Bonneville Dam, 0.5% of wild smolts and 1.6% of hatchery-raised smolts were subsequently detected on the Rice Island tern colony (Collis *et al.* 2001b). PIT tag data also determined that steelhead experienced higher predation rates (0.6% to 8.1% on East Sand Island and 1.3% to 9.4% on Rice Island) than chinook salmon (0.2% to 2.0% on East Sand Island and 0.6% to 1.6% on Rice Island).

There are some important uncertainties from estimating predation rates for Caspian terns. Predation impacts derived from PIT tags, while more direct than those derived from bioenergetics models, represent minimum estimates of the proportion of stocks consumed--an unknown number of tags are regurgitated/defecated off-colony or removed by wind and water erosion, tags may be damaged and undetectable, and not all tags are detected (Ryan *et al.* 2001, Collis *et al.* 2001b, Collis *et al.* 2002). Also, predation rates vary annually and by the methodology used to make the estimate, making it difficult to derive a single predation rate. Although there is good correspondence of predation rates between methodological estimates, utilizing the upper and lower bounds of the predation rates to bracket potential recovery improvements represent the most reliable approach that currently should be used to assess potential impacts of smolt predation by Caspian terns. Finally, it is clear that predation rates are not uniform for all salmon species, thus evaluation of the impact of Caspian tern predation should be species or ESU-specific, to the extent possible.

## RELOCATION EFFORTS

Efforts to relocate the terns to East Sand Island began in 1999, and these efforts have apparently succeeded in reducing consumption of smolts without affecting tern productivity. The Caspian Tern Working Group relocated the Caspian tern colony from Rice Island to East Sand Island--a site lower in the estuary with abundant alternate prey sources--in an attempt to decrease losses of juvenile salmonids. Over the last few years, consumption of salmonids in the estuary has been lower than previously, while consumption of alternative prey species has increased. Relocating the colony to East Sand Island, which is lower in the estuary and closer to periodically abundant Pacific herring [Clupeidae] and anchovies [Engraulidae] has contributed to the reduction. In 2000, salmonid consumption for both islands combined was estimated at 7.3 million smolts, which is 4.4 million less than in 1999--the last time a substantial number of terns nested on Rice Island (Collis *et al.* 2001a, USFWS 2001). In 2001, salmonid consumption was estimated at 5.9 million smolts, which is 5.9 million less than in 1999 (Collis *et al.* 2001a).

Caspian tern diets also shifted following relocation from Rice Island. Observed diets, which consisted of almost exclusively salmonids at Rice Island (77% in 1999 and 90% in 2000), shifted to 46%, 47% and 33% salmonids at East Sand Island in 1999, 2000 and 2001 respectively (Collis *et al.* 2001a, Roby *et al.* 2003). These data represent substantial declines in juvenile salmonid mortalities from Caspian tern predation. These observational data were substantiated by PIT tag detections on the two islands in 1999 and 2002. Significantly fewer PIT tags detected per nest on East Sand Island in 1999 and 2000 than were detected on Rice Island in 1999 and 2000 (Table 2).

Table 2. Ratio of PIT tags detected per Caspian tern nesting pair on East Sand Island and Rice Island in 1999 and 2000.

	1999	2000
<b>Rice Island</b>	0.59	1.25
<b>East Sand Island</b>	0.32	0.35

In addition to reductions in Caspian tern predation on juvenile salmonids, relocation efforts have not significantly impaired Caspian tern reproductive performance. Nesting success has been substantially higher for Caspian terns nesting on East Sand Island as compared to Rice Island (Roby *et al.* 2003), and productivity at East Sand Island in 2001 was the highest recorded for terns nesting in the estuary (Collis *et al.* 2001a). It appears that relocating terns to East Sand Island accomplished the goal of reducing consumption of juvenile salmon without adversely affecting tern population growth rates.

## PREDATION IMPACT OF CASPIAN TERNS ON EAST SAND ISLAND

### Data and Analyses

In this report, we focus on predation on steelhead by Caspian terns nesting on East Sand Island from 1999-2002. We focus on steelhead because they are the most heavily affected of the outmigrating juvenile salmonids (Ryan *et al.* 2003, Roby *et al.* 2003); estimates of the potential benefit of reducing Caspian tern predation are thus the greatest for steelhead and would encompass potential benefits afforded to other salmonid species. We focus on the Caspian tern colonies on East Sand Island in the lower estuary of the Columbia River, because the colony represents the majority of the West Coast Caspian tern population, and we focus on 1999-2002 because this represents the time period, after relocation from Rice Island, during which this colony has persisted in the Columbia River estuary. In general, both analytical techniques (PIT tag detections; bioenergetics modeling) found a positive relationship between the number of Caspian terns on East Sand Island and the predation rate on juvenile salmonids, *i.e.* the proportion of available juvenile salmonids consumed (Fig. 5).

Bioenergetics modeling, which has been used to estimate the effect of Caspian tern predators on juvenile salmonids on Rice Island (Roby *et al.* 2003), was used to calculate predation rates (%) (estimated # of steelhead consumed/estimated # of steelhead available in the estuary x 100) using updated and refined estimates of the number of outmigrating steelhead that run the river or are transported to below Bonneville Dam (Table 3; Fig. 6).

Table 3. Estimates of nesting population, the number of steelhead consumed, the number of steelhead available, and predation rates of Caspian terns nesting on East Sand Island using bioenergetics modeling (D. Lyons and D. Marsh, unpublished data).

Year	# tern pairs	# of steelhead consumed	# of steelhead available	Predation Rate % (95% C.I.)
1999	547	72,844	13,501,917	0.5 (0.3 - 0.8)
2000	8513	842,433	13,359,935	6.3 (4.4 - 8.3)
2001	8982	571,441	13,560,423	4.2 (3.2 - 5.2)
2002	9933	741,772	12,124,528	6.1 (4.8 - 7.4)

Although the relationship between tern abundance and predation rate is not known with certainty, possibilities include linear, exponential, asymptotic, and logistic. A simple linear response of the predation rate on all steelhead to the number of Caspian terns nesting on East Sand Island during the breeding seasons of 1999-2002 appears to describe the relationship.<sup>2</sup> Further support for a linear relationship between estimates of predation rate and the number of terns nesting on East Sand Island comes from per capita consumption rates (# of smolts consumed/adult tern), which have been relatively constant throughout the range of colony sizes

<sup>2</sup> Analyses of influence statistics on linear regressions of PIT tag recoveries on Caspian Tern numbers demonstrated that the 1999 data point exacted little leverage on the regression analyses (P. Wilson, USFWS, unpublished data). He concluded that regressions including the 1999 data resulted in reasonable representations of the data, provided they were modeled through the origin.

on East Sand Island from 1999-2003. The per capita consumption rate in 1999 (mean = 437.5 salmonids) was virtually the same as that in 2000 (mean = 431.1 salmonids), despite a ten-fold difference in Caspian Tern numbers (1094 in 1999 vs 17,026 in 2000) (D. Roby and D. Lyons, unpublished data). A relatively constant per capita consumption rates for salmonids has also been seen on Rice Island over a range of tern population numbers from 1997-2000. The per capita consumption rate on Rice Island in 1999 (mean = 784.1 salmonids) was virtually the same as in 2000 (mean = 739.7 salmonids) despite a ten-fold difference in colony size (8328 nesting pairs in 1999 vs. 588 nesting pairs in 2000) D. Roby and D. Lyons, unpublished data). This suggests that the Caspian Tern predation rate is not affected by *predator density*, at least over the range of values experienced from 1999-2003. While non-linear relationships described the data just as well as the linear one, per capita consumption rates associated with an exponential relationship (increasing with an increase in terns), logistic relationship (parabolic over the range of tern numbers), or asymptotic relationship (decreasing with an increase in tern numbers) were not observed.

As both analytical techniques produced similar results, we focus on the PIT tag detection analytical technique--which has also been used to estimate the effect of Caspian tern predators on juvenile salmonid outmigrants (Ryan *et al.* 2003)--to calculate estimates of predation rates on steelhead. Moreover, as the PIT tag detection approach makes possible ESU-specific predation rate estimates, subsequent analyses presented use PIT tag predation rates. Estimates of predation rates (%) from this approach (# PIT tags detected on East Sand Island/# PIT tags detected at Bonneville Dam x 100) also showed a linear response to the number of Caspian terns nesting on East Sand Island during the breeding seasons of 1999-2002 (Figure 7).

We then used these estimates of predation rate (derived from the number of terns) to derive the likely impact on the overall population trajectory for steelhead in the Columbia River. We first calculated the median population growth rate lambda ( $\lambda$ ) using the methods in Holmes (2001) and McClure *et al.* (2003). These methods have been: developed for data sets with high sampling error and age-structure cycles (Holmes 2001), extensively tested using simulations for threatened/endangered populations as well as for low-risk stocks (Holmes 2004), and have been cross-validated with time series data (Holmes and Fagan 2002). We chose this parameter for two reasons. First, population growth rate is an essential parameter in viability assessments and a primary predictor of extinction risk. Second, calculating population growth rate in this manner (annualized), provides a standard metric for comparison between species (or ESUs) with different generation times.

We next calculated the deterministic change in population growth rates given standard reductions in mortality. Because the vast majority of steelhead in the interior Columbia are semelparous, the percent increase in  $\lambda$  attributable to an increase in survival at a particular life history stage can be approximated as:

$$\Delta\lambda = \left[ \left( \frac{S_{new}}{S_{old}} \right)^{1/G} - 1 \right] \times 100$$

where  $S_{old}$  is the initial survival rate before recovery action,  $S_{new}$  is the survival rate following the recovery action, and  $G$  is the average generation time (McClure *et al.* 2003). This calculation assumes that the change in survival due to tern predation is independent of density and of changes in survival elsewhere in the salmonid life history. We did not use a formal Leslie matrix analysis to estimate changes in population growth rates because data to parameterize a detailed model for steelhead were not available.

We estimated the impact of Caspian tern predation on the population growth rate ( $\lambda$ ) of all steelhead in the Columbia River basin to compare predation rate estimates from bioenergetics modeling and PIT tag detection approaches. Because of the similarity in the results between the two approaches, we present both for comparative purposes (Table 4).

Table 4. Estimated predation rate (PR) and percent increase in the population growth rate ( $\lambda$ ) of all steelhead in the Columbia River basin if populations of Caspian Terns breeding on East Sand Island are reduced to that number, assuming a linear relationship between predation rates and Caspian Tern breeding population size (see Figs. 6 and 7). Calculations used the predation rate estimated for 20,000 terns from linear regressions of (a) *recovery of PIT-tags* and (b) *bioenergetics modeling*, and the generation time for

(a)

Number of tern pairs	PR	Increase in $\lambda$ (%)
10000	8.7	0.0
9375	8.1	0.1
8750	7.6	0.2
8125	7.0	0.4
7500	6.5	0.5
6875	6.0	0.6
6250	5.4	0.7
5625	4.9	0.9
5000	4.3	1.0
4375	3.8	1.1
3750	3.2	1.2
3125	2.7	1.3
2500	2.2	1.4
1875	1.6	1.6
1250	1.1	1.7
625	0.5	1.8
0	0.0	1.9
		4.79*

(b)

Number of tern pairs	PR	Increase in $\lambda$ (%)
10000	6.1	0.0
9375	5.7	0.1
8750	5.3	0.2
8125	4.9	0.3
7500	4.6	0.3
6875	4.2	0.4
6250	3.8	0.5
5625	3.4	0.6
5000	3.0	0.7
4375	2.6	0.7
3750	2.3	0.8
3125	1.9	0.9
2500	1.5	1.0
1875	1.1	1.1
1250	0.8	1.2
625	0.4	1.2
0	0.0	1.3
		4.79*

the Snake River basin\*.

The predation rate for 10,000 Caspian tern pairs on all steelhead was estimated using the regression equations generated using both approaches. Reductions in predation rate corresponding to lowered tern population sizes were used to model the potential increase in  $\lambda$ , assuming all steelhead mortality attributable to terns is not compensated for by mortality due to other sources. The maximum *percent* increase in  $\lambda$  corresponding to complete elimination of mortality due to tern predation was 1.9% using the PIT-tag estimate of predation rate and 1.3%

using the bioenergetics modeling estimate of predation rate; the proportional increase in  $\lambda$  corresponding to a 50% reduction of mortality due to tern predation was 0.97% using the PIT-tag estimate of predation rate and 0.67% using the bioenergetics modeling estimate of predation rate.

To investigate how variation in generation times in Columbia River basin steelhead influenced model output, we also estimated the potential increase in  $\lambda$  using the recovery of PIT tags for all steelhead using the range of generation times (4.27 – 4.85) that have been estimated for steelhead ESUs in the Columbia River basin. This resulted in maximum increases in  $\lambda$  (corresponding to a minimum breeding population size of 0 tern pairs) that ranged from a low of 1.88% to a high of 2.44%.

As the PIT tag detection approach enables ESU-specific estimates of predation rate (and hence proportion increase in  $\lambda$ ), we used the life-cycle model to estimate impact of Caspian tern predation on the population growth rate ( $\lambda$ ) of steelhead ESUs using predation rates estimated from PIT tag detections (Table 5). Predation rates for 10,000 Caspian tern pairs on four of the five ESA-listed steelhead ESUs were estimated using linear regression (Figs. 8-11). Reductions in predation rate corresponding to lowered tern population sizes were used to model the potential increase in  $\lambda$ , again assuming all steelhead mortality attributable to terns is additive, *i.e.* not compensated for by mortality due to other sources. The maximum proportional increase in  $\lambda$  corresponding to complete elimination of mortality due to tern predation ranged from 1.6% to 4.9% under the most optimistic assumptions (hatchery fish do not reproduce) and 0.7% to 1.0% under the most pessimistic assumptions (hatchery fish reproduce at the same rate as wild-born fish).

Although this analysis was restricted to assessing the potential effects of reducing Caspian tern predation, McClure *et al.* (2003) estimated the effects of other potential conservation actions, including changes to the hydropower system and reductions in harvest. Because these estimates were calculated using similar methods, they are comparable to our results, and we present them here to provide context.

Table 5. Estimated predation rates (PR), % increase in  $\lambda$  predicted from predation rates at those levels, and population growth rate ( $\lambda$ ) of four of the five listed steelhead ESUs in the Columbia River basin given a range of Caspian Terns breeding on East Sand Island. Calculations used the predation rate estimated from the linear regression of ESU-specific PIT-tag recoveries (see Figs. 7-10). Generation times\* and lambda values (1980-2000) for each ESU are taken from McClure *et al.* (2003), where  $\lambda$  has been estimated under different assumptions about hatchery fish reproduction ( $\lambda =$  hatchery fish on the spawning grounds do not reproduce and  $\lambda_h =$  hatchery fish reproduce at the same rate as wild-born fish).

# Pairs	Snake River				Upper Columbia River				Middle Columbia River				Lower Columbia River			
	PR	% $\Delta\lambda$	$\lambda$	$\lambda_h$	PR	% $\Delta\lambda$	$\lambda$	$\lambda_h$	PR	% $\Delta\lambda$	$\lambda$	$\lambda_h$	PR	% $\Delta\lambda$	$\lambda$	$\lambda_h$
10000	8.7	0.0	1.02	0.96	16.4	0.0	1.00	0.63	8.7	0.0	0.97	0.95	6.9	0.0	0.92	0.81
9375	8.2	0.1	1.02	0.96	15.3	0.3	1.00	0.63	8.2	0.1	0.97	0.95	6.5	0.1	0.92	0.81
8750	7.6	0.2	1.02	0.96	14.3	0.6	1.01	0.63	7.6	0.2	0.97	0.95	6.1	0.2	0.92	0.81
8125	7.1	0.4	1.02	0.96	13.3	1.0	1.01	0.64	7.1	0.4	0.97	0.95	5.6	0.3	0.92	0.81
7500	6.5	0.5	1.02	0.96	12.3	1.3	1.01	0.64	6.5	0.5	0.98	0.96	5.2	0.4	0.92	0.81
6875	6.0	0.6	1.03	0.97	11.2	1.6	1.02	0.64	6.0	0.6	0.98	0.96	4.8	0.5	0.92	0.81
6250	5.4	0.7	1.03	0.97	10.2	1.9	1.02	0.64	5.4	0.7	0.98	0.96	4.3	0.6	0.93	0.82
5625	4.9	0.9	1.03	0.97	9.2	2.2	1.02	0.64	4.9	0.8	0.98	0.96	3.9	0.7	0.93	0.82
5000	4.4	1.0	1.03	0.97	8.2	2.5	1.02	0.65	4.4	1.0	0.98	0.96	3.5	0.8	0.93	0.82
4375	3.8	1.1	1.03	0.97	7.2	2.8	1.03	0.65	3.8	1.1	0.98	0.96	3.0	0.9	0.93	0.82
3750	3.3	1.2	1.03	0.97	6.1	3.1	1.03	0.65	3.3	1.2	0.98	0.96	2.6	1.0	0.93	0.82
3125	2.7	1.3	1.03	0.97	5.1	3.4	1.03	0.65	2.7	1.3	0.98	0.96	2.2	1.1	0.93	0.82
2500	2.2	1.5	1.04	0.97	4.1	3.7	1.04	0.65	2.2	1.4	0.98	0.96	1.7	1.2	0.93	0.82
1875	1.6	1.6	1.04	0.98	3.1	4.0	1.04	0.66	1.6	1.6	0.98	0.96	1.3	1.3	0.93	0.82
1250	1.1	1.7	1.04	0.98	2.0	4.3	1.04	0.66	1.1	1.7	0.99	0.97	0.9	1.4	0.93	0.82
625	0.6	1.8	1.04	0.98	1.0	4.6	1.05	0.66	0.5	1.8	0.99	0.97	0.4	1.5	0.93	0.82
0	0.0	1.9	1.04	0.98	0.0	4.9	1.05	0.66	0.0	1.9	0.99	0.97	0.0	1.6	0.93	0.82
			4.79*			4.27*					4.85*				4.63*	

For comparison, we include the results of similar modeling exercises conducted to estimate increases in population growth rates anticipated from changes to hydropower or harvest operations (Table 6). The estimates for hydropower improvement come from changes to improve passage for both adults and juveniles called for in NOAA Fisheries’ FY 2000 Biological Opinion on operation of the Federal Columbia River Hydropower System (FCRPS) (NMFS 2000b, McClure *et al.* 2003). The estimates for harvest elimination come from McClure *et al.* (2003) and have been largely realized already. Thus, the potential increase in  $\lambda$  that may be realized from eliminating Caspian tern predation (1.6 - 4.9%) is equivalent to that of hydropower improvements but well below that of elimination of harvest reductions, all else being equal.

Table 6. Potential increases (%) in population growth rate of Columbia River basin steelhead ESUs corresponding to passage improvements in the Federal Columbia River Hydropower System and elimination of harvest.

	Snake River	Upper Columbia River	Middle Columbia River	Lower Columbia River
Caspian Tern predation (eliminated)	1.9	4.9	1.9	1.6
Caspian Tern predation (halved)	1.0	2.5	1.0	0.8
Hydropower improvements	1-2	2.0-4.0	2.0-3.0	0.0-1.0
Harvest elimination	4.0-7.0	8.0	4.0	6.0-8.0

### ADDITIONAL AVIAN PREDATION IMPACTS

Other avian predators of juvenile salmonids in the Columbia River estuary include Double-crested Cormorants (*Phalacrocorax auritis*), California Gulls (*Larus californicus*), Ring-billed Gulls (*L. delawarensis*), and members of the Glaucous-winged/Western Gull hybrid complex (*L. glaucescens/L. occidentalis*) (Roby *et al.* 1998, Collis *et al.* 2001a). Calculations of predation rates based upon the PIT tag detection approach for cormorants nesting on East Sand Island are provided for purposes of comparison and to place Caspian tern predation in context with other avian predation in the Columbia River basin (Table 7).

Table 7. Comparison of estimated predation rates (%) for Double-crested cormorants and Caspian terns breeding on East Sand Island on all steelhead in the Columbia River basin. Predation rates were calculated as the percent of PIT tags detected at Bonneville Dam that were later detected on cormorant colonies on East Sand Island. *Note: Detection efficiency for PIT tags on the East Sand Island cormorant colony is probably much lower than on the East Sand Island tern colony, thus, the estimated predation rates by cormorants are biased lower for terns*

	1999	2000	2001	2002
<b>Caspian terns</b>	0.8	6.7	7.7	9.2
<b>Double-crested cormorants</b>	0.6	2.5	1.2	0.7

Analyses of PIT tag detections on East Sand Island cormorant colonies made it possible to compare these sources of mortality by ESU; these methods found not insubstantial predation rate estimates from double-crested cormorants as compared to Caspian terns (Table 8).

Table 8. Estimated predation rates (%) for Caspian terns and Double-crested cormorants breeding on East Sand Island on four of the five ESA-listed steelhead ESUs in the Columbia River basin. Predation rates were calculated as the percent of PIT tags detected at Bonneville Dam that were later detected on cormorant colonies on East Sand Island.

	Caspian terns				Double-crested cormorants			
	1999	2000	2001	2002	1999	2000	2001	2002
<b>Snake River</b>	0.7	5.8	7.2	10.6	0.6	2.7	1.3	0.7
<b>Upper Columbia River</b>	0.6	10.9	25.2	9.3	0.6	2.0	0.8	0.9
<b>Middle Columbia River</b>	0.4	6.8	10.0	7.2	0.4	1.9	0.8	0.3
<b>Lower Columbia River</b>	0.4	6.1	6.7	6.3	0.3	0.8	1.1	0.2

### **AVIAN PREDATION UPRIVER OF THE COLUMBIA RIVER ESTUARY**

Substantial numbers of salmonid smolts are also lost to avian predators--terns, cormorants, and gulls--upriver of East Sand Island. In particular, a significant number of Caspian terns nest on Crescent Island in the mid-Columbia River. The proportion of their diet represented by salmonid smolts is greater than for terns nesting on East Sand Island (Collis *et al.* 2001a), and comparisons of the potential impact of this predation remains an important consideration in any analysis of avian predation impacts in the Columbia River basin (Table 9).

Table 9. Estimated predation rates (%) for Caspian terns and all birds breeding on Crescent Island on all steelhead ESUs in the Columbia River basin. Predation rates were calculated as the percent of PIT tags detected at Lower Monumental Dam that were later detected on *Caspian tern* colonies on Crescent Island (B. Ryan, unpubl. data).

	1999	2000	2001	2002
<b>Caspian terns</b>	4.1	1.7	13.2	7.2
<b>Other birds</b>	0.4	2.0	7.9	2.9

### **CONCLUSIONS**

Many evaluations of salmonid predation by Caspian terns in the Columbia River estuary have indicated that substantial numbers of juvenile salmonids are being consumed (Roby *et al.* 1998,

Collis *et al.* 2001a, 2001b, Ryan *et al.* 2001, Ryan *et al.* 2003, Roby *et al.* 2003). The two approaches that have been used to evaluate the extent of that impact yield similar results and appear to provide reasonable estimates of predation rates. The PIT tag recovery approach has also revealed species-specific vulnerability to Caspian tern predation--steelhead are substantially more susceptible to tern predation than yearling chinook. Efforts to reduce predation by moving the colony from Rice Island (more central to the Columbia River estuary) to East Sand Island (located towards the mouth of the Columbia River) have successfully decreased overall predation as fewer salmon are consumed per nest on East Sand Island. The decrease in consumption has been substantial. However, PIT tag data on predation rates needs to be further collected at East Sand to confirm initial observations and to document that the relocation efforts have been successful in reducing impacts for all ESUs (particularly for steelhead).

Several factors must be considered when interpreting the results of these calculations. Perhaps the most important factor is that this type of calculation assumes that there is no compensatory mortality later in the life cycle, and that the benefits from any reduction in tern predation are fully realized. In their assessment of predation impact by Rice Island terns on salmonids in 1997-1998, Roby *et al.* (2003) hypothesized that tern predation was 50% additive. Given these limitations and uncertainties, the estimates of percent change in population growth rates should be viewed as maximum potential improvements. Realized improvements in population growth would likely be lower from any management action that reduces Caspian tern predation impacts on salmonid ESUs. These results may not be as easy to achieve as they are to calculate. It is also important to recognize that other factors such as ocean conditions may also influence population growth rate to a greater degree than the potential gains that may be realized from reducing predation by one species of avian predator on one island located in the lower estuary of the Columbia River basin.

Not all listed salmonid populations have declined because of the same factors or combination of factors, and not all populations could be expected to respond positively to any particular management measure or combination of measures. In the case of the avian predator populations discussed here, artificial islands (such as Rice Island) have promoted the development of unprecedented large colonies of piscivorous birds with subsequent increases in losses of juvenile salmonids from predation.

Finally, additional factors may influence the gains in population growth rate that may be realized from reducing predation rates on outmigrating juvenile salmonids. These include, but are not limited to: hydropower operations, harvest rates, habitat conditions, the influence of hatchery fish and exotic species, ocean conditions, and climate change.

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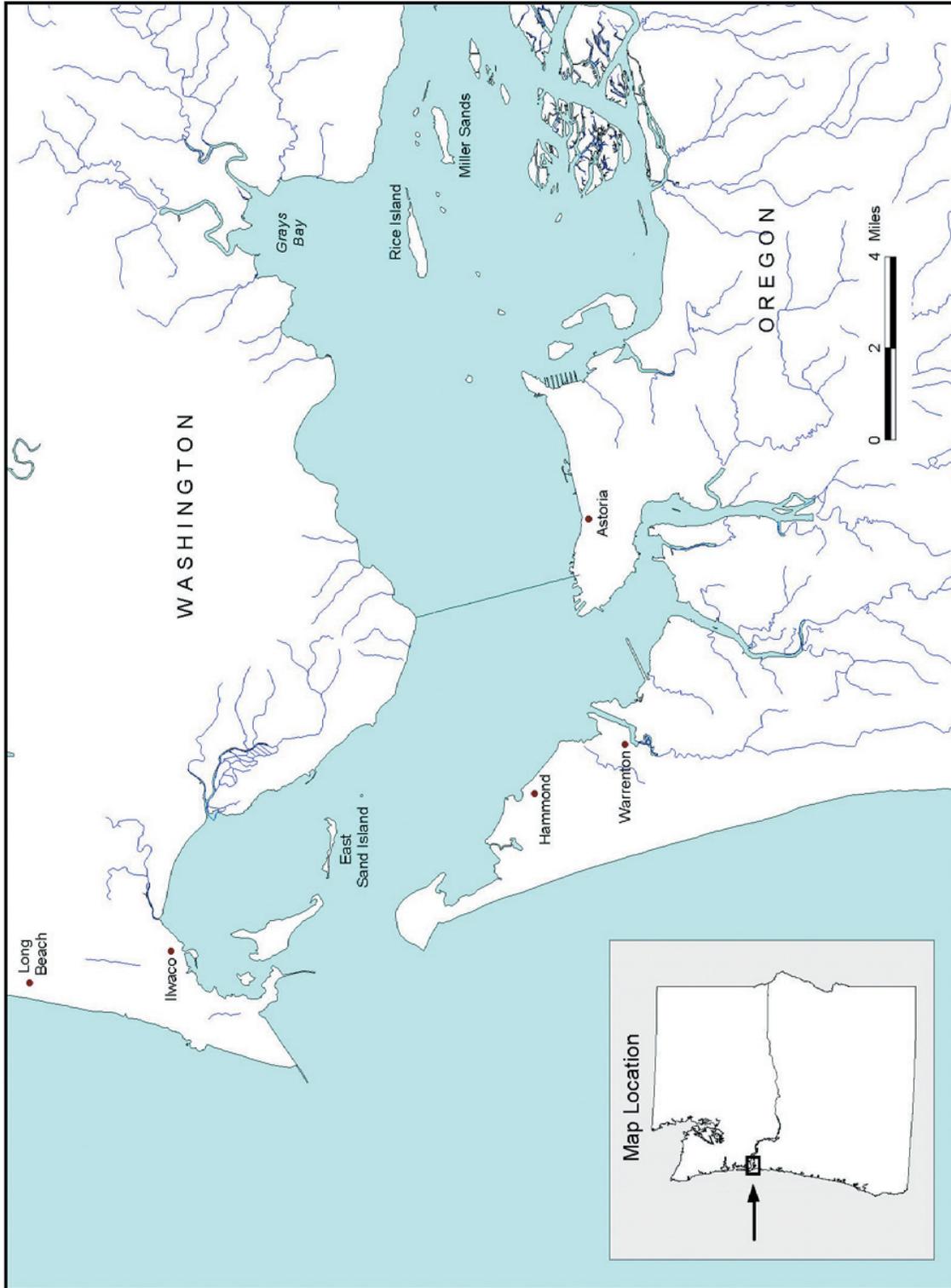


Figure 1. Map of the Columbia River estuary showing the relative locations of East Sand and Rice Islands, sites of Caspian tern nesting colonies.

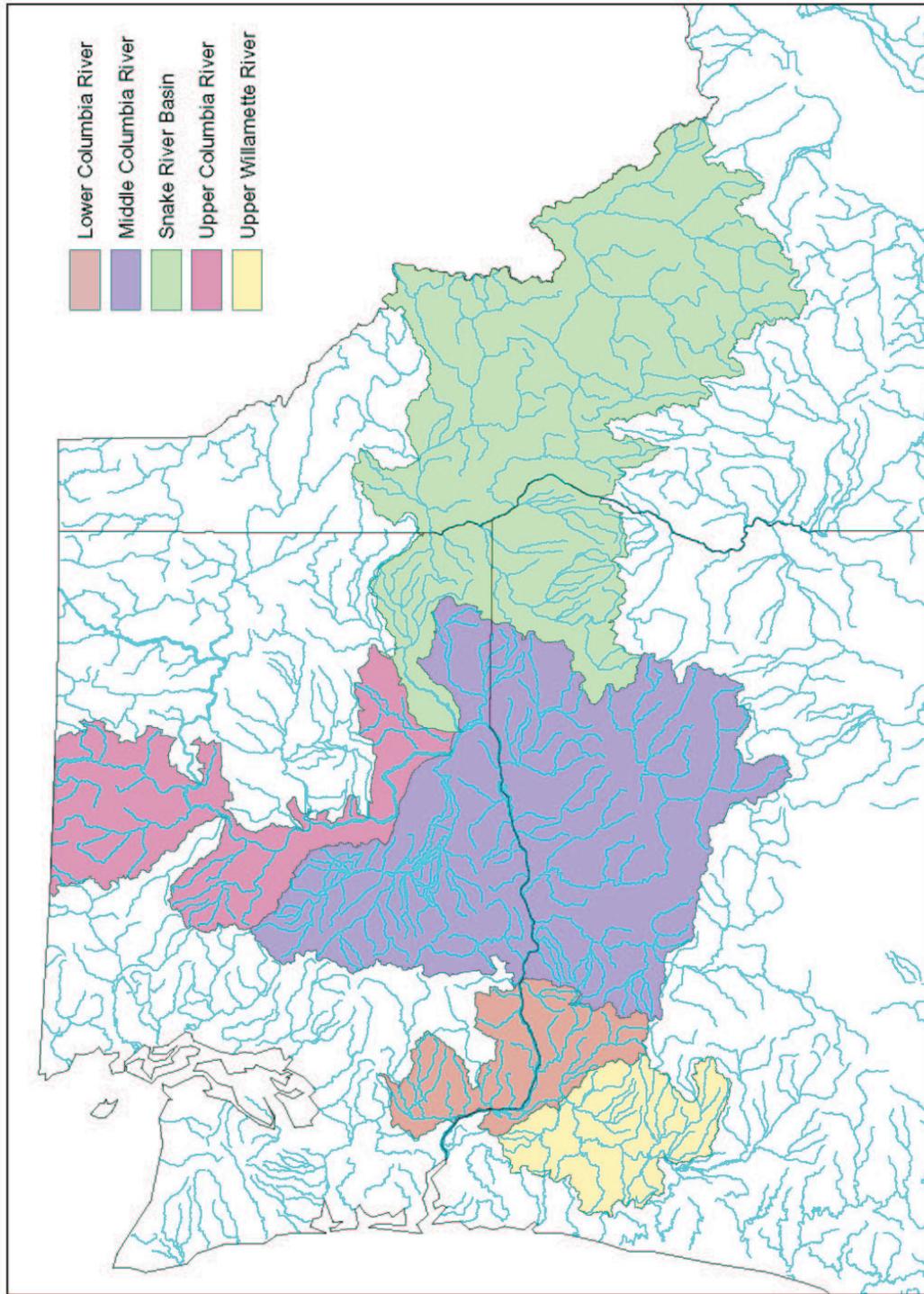


Figure 2. Map of Columbia River Basin showing the locations of the ESA-listed Lower Columbia River, Upper Willamette River, Middle Columbia River, Upper Columbia River and Snake River steelhead ESUs.

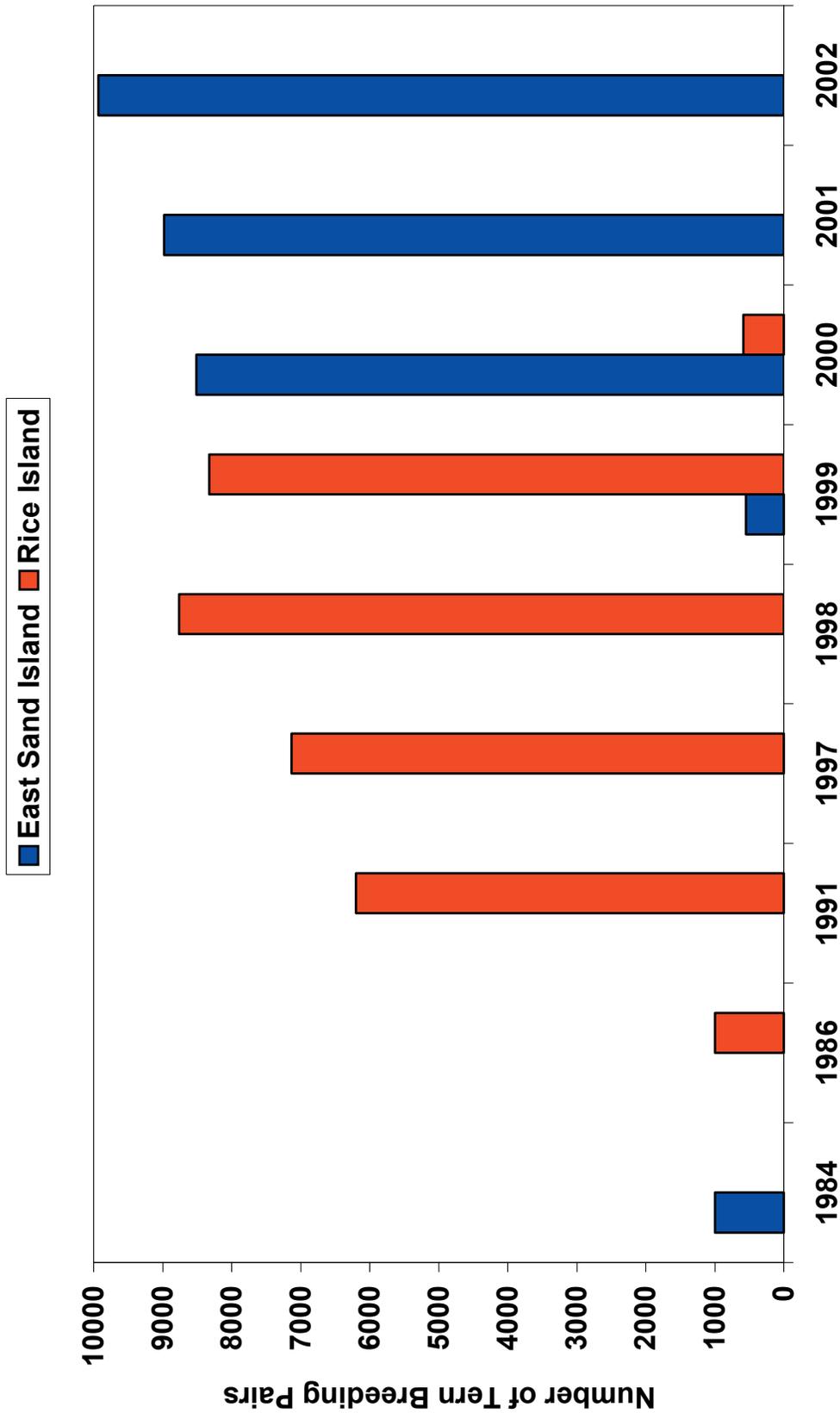


Figure 3. Numbers of Caspian terns nesting on islands in the Columbia River estuary since 1984.

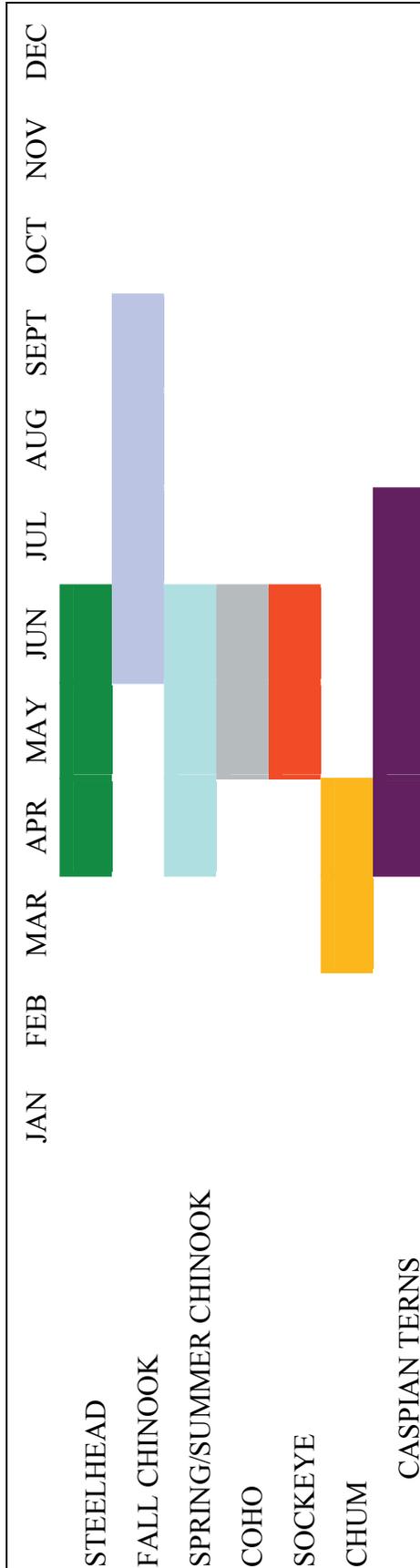
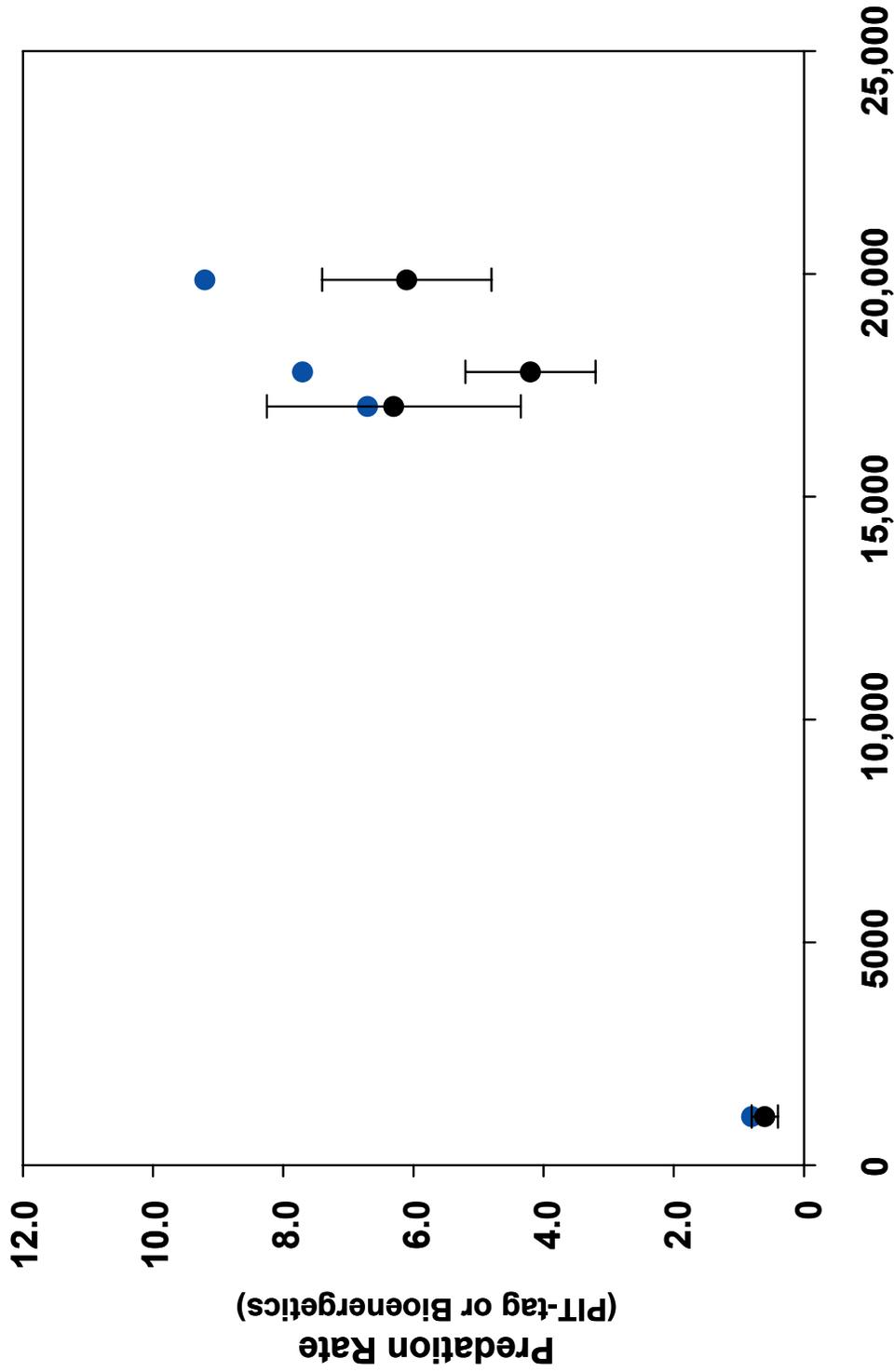


Figure 4. Arrival times of juvenile salmonids and nesting period of Caspian terns in the Columbia River estuary.



**Number of Caspian Terns Breeding on East Sand Island**

Figure 5. Estimated predation rates on *all Columbia River basin steelhead* in the Columbia River estuary by Caspian Terns (1999-2002) using bioenergetics modeling (black symbols) and recovery of PIT tags (blue symbols). Error bars on bioenergetics estimates represent 95% confidence limits.

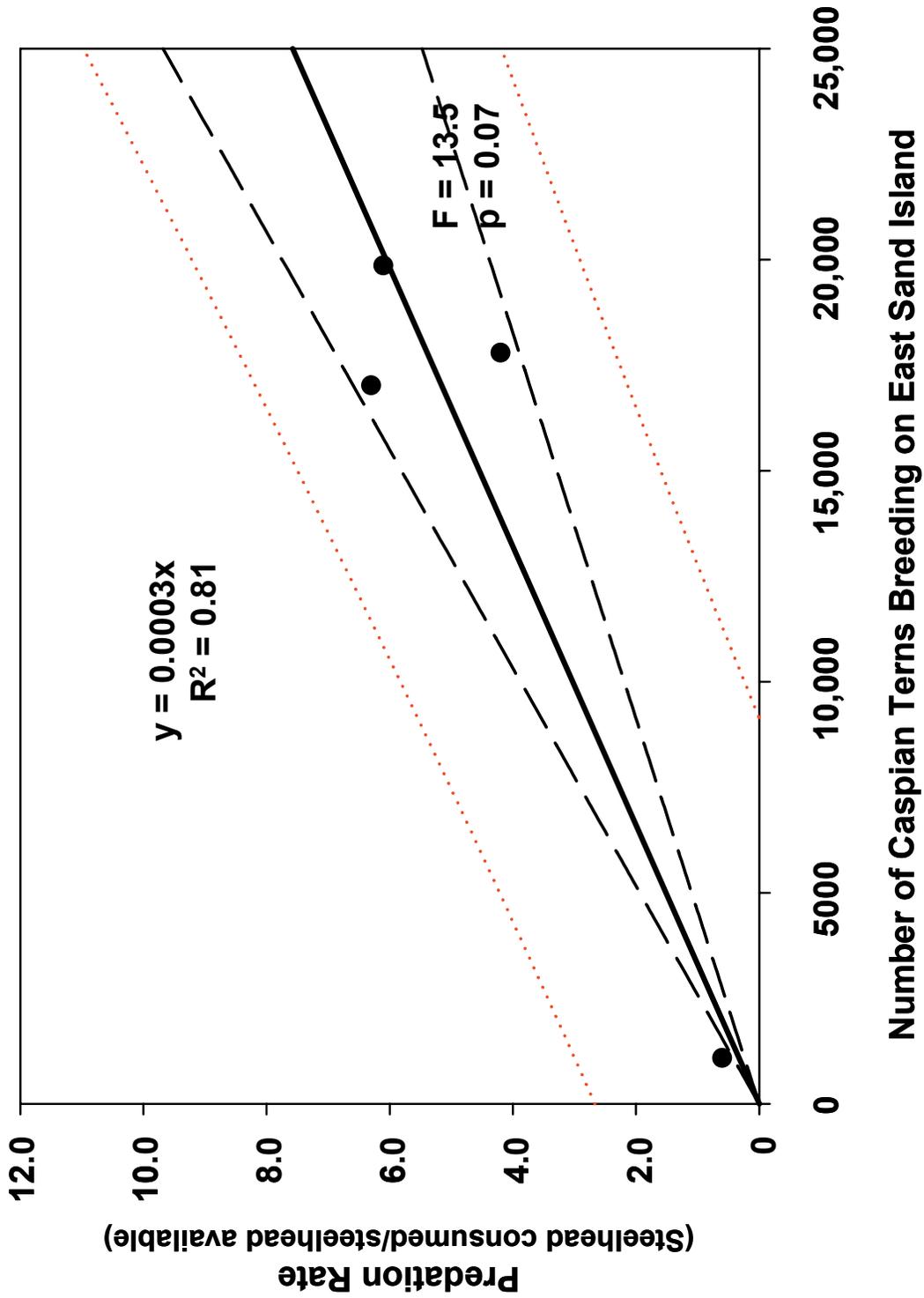


Figure 6. Linear regression of predation rates on *all Columbia River basin steelhead* in the Columbia River estuary by Caspian Terns breeding on East Sand Island (1999-2002) estimated using *bioenergetics modeling*. Dashed black lines represent 95% confidence limits; dotted red lines represent 95% prediction limits.

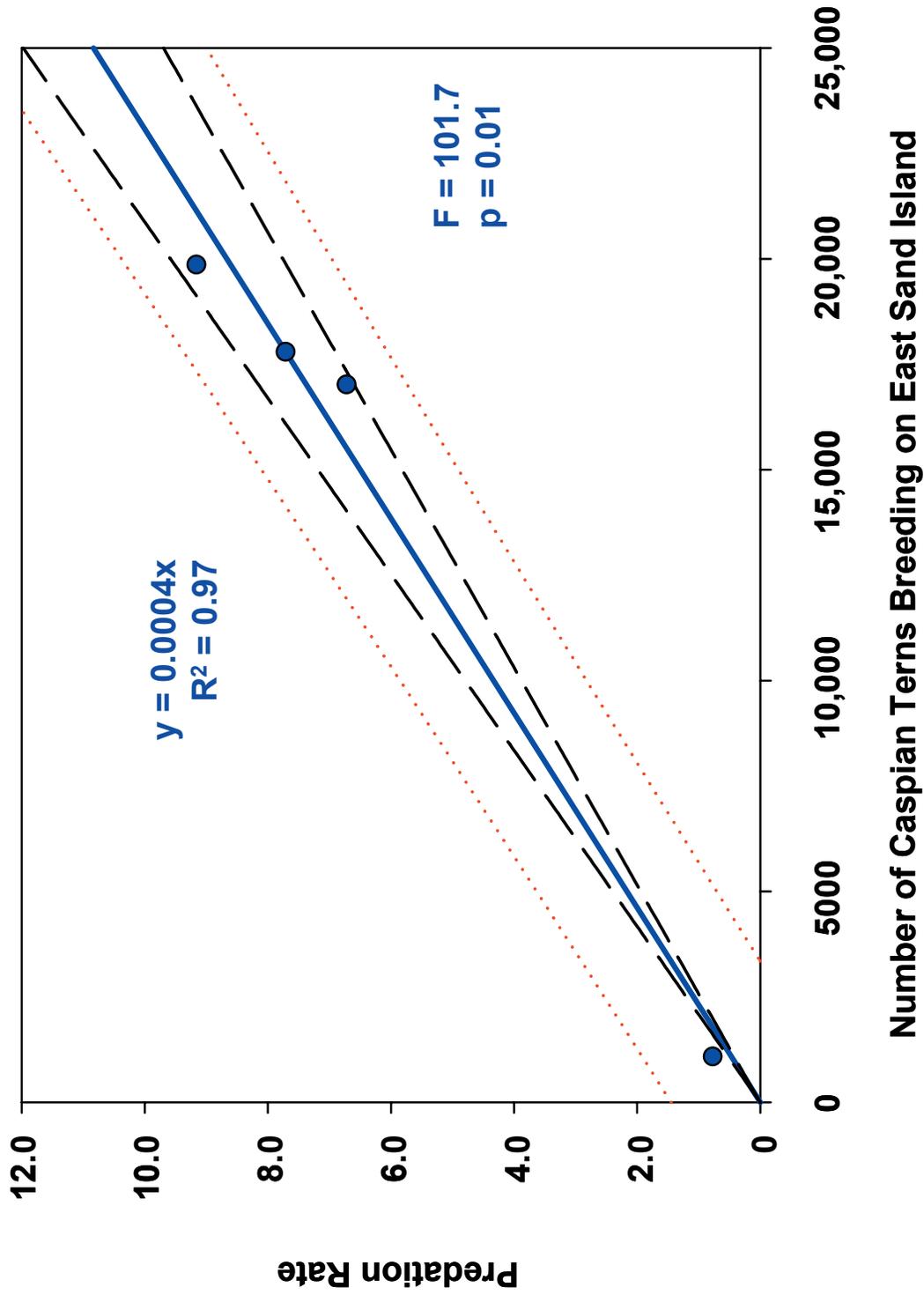
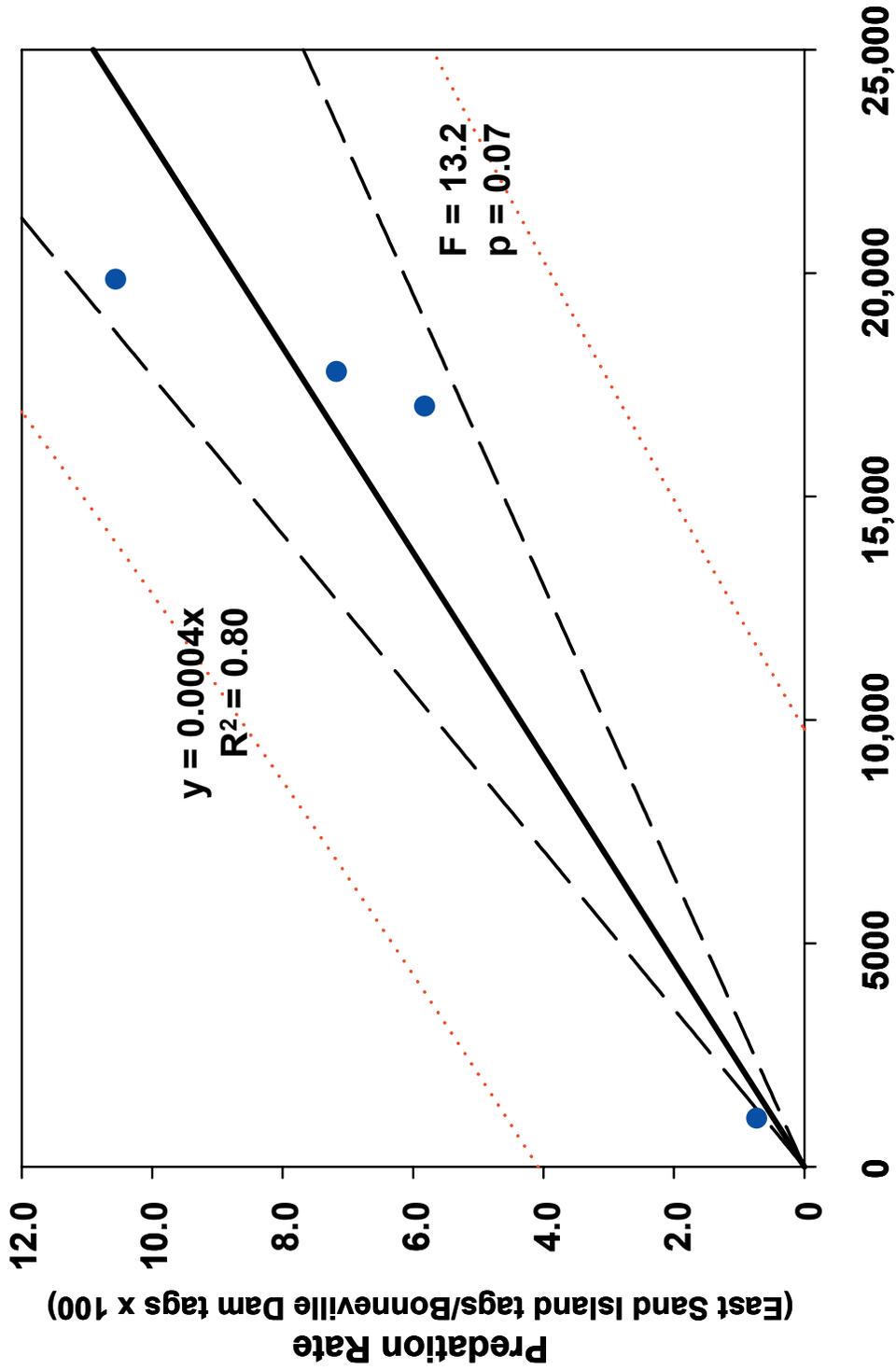
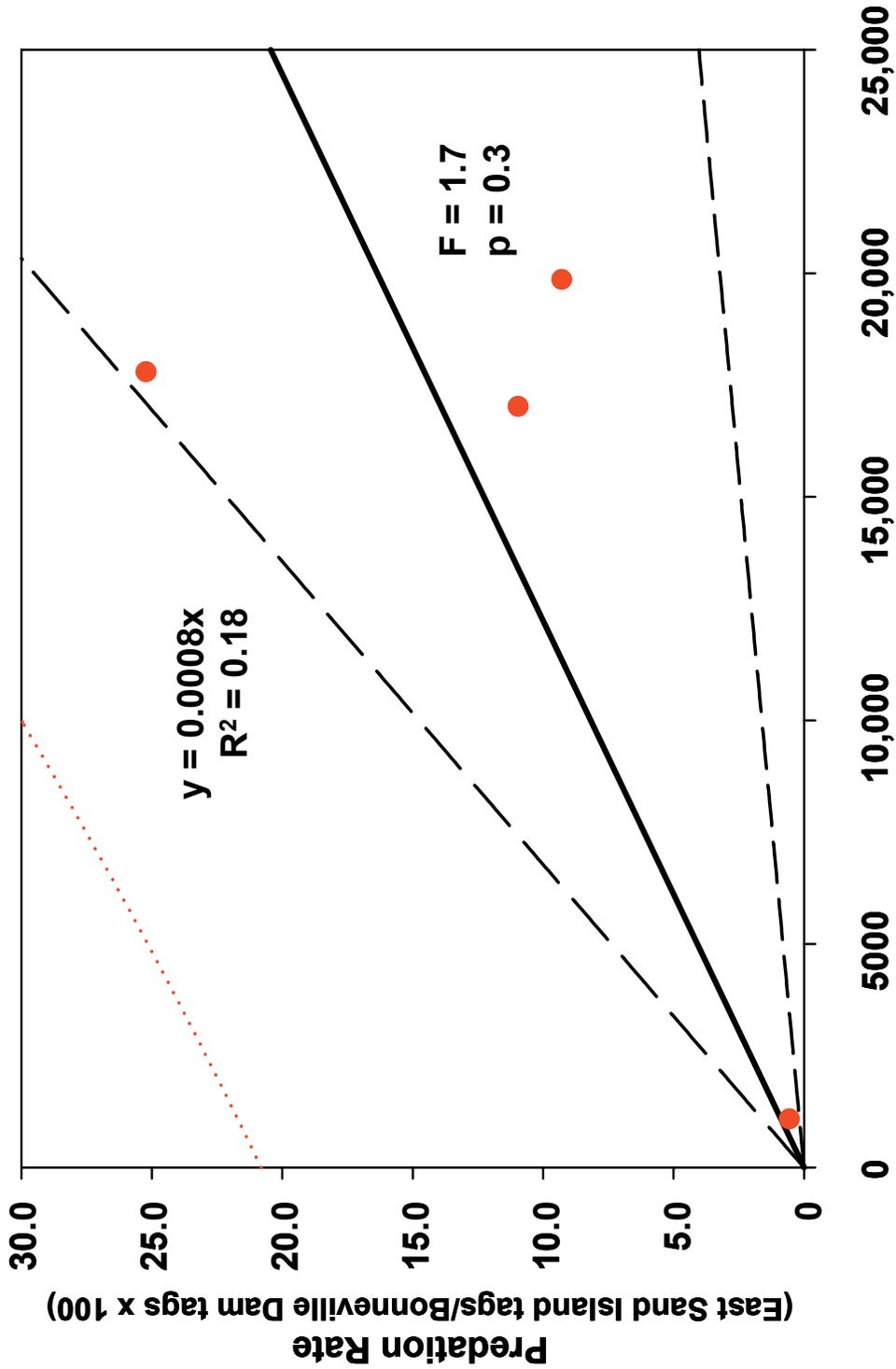


Figure 7. Linear regression of predation rates on *all Columbia River basin steelhead* in the Columbia River estuary by Caspian Terns breeding on East Sand Island (1999-2002) estimated using *recovery of PIT tags*. Dashed black lines represent 95% confidence limits; dotted red lines represent 95% prediction limits.



**Number of Caspian Terns Breeding on East Sand Island**

Figure 8. Linear regression of predation rates on the Snake River steelhead ESU in the Columbia River estuary by Caspian Terns breeding on East Sand Island (1999-2002) estimated using recovery of PIT tags. Dashed black lines represent 95% confidence limits; dotted red lines represent 95% prediction limits.



**Number of Caspian Terns Breeding on East Sand Island**

Figure 9. Linear regression of predation rates on the *Upper Columbia River steelhead ESU* in the Columbia River estuary by Caspian Terns breeding on East Sand Island (1999-2002) estimated using *recovery of PIT tags*. Dashed black lines represent 95% confidence limits; dotted red lines represent 95% prediction limits.

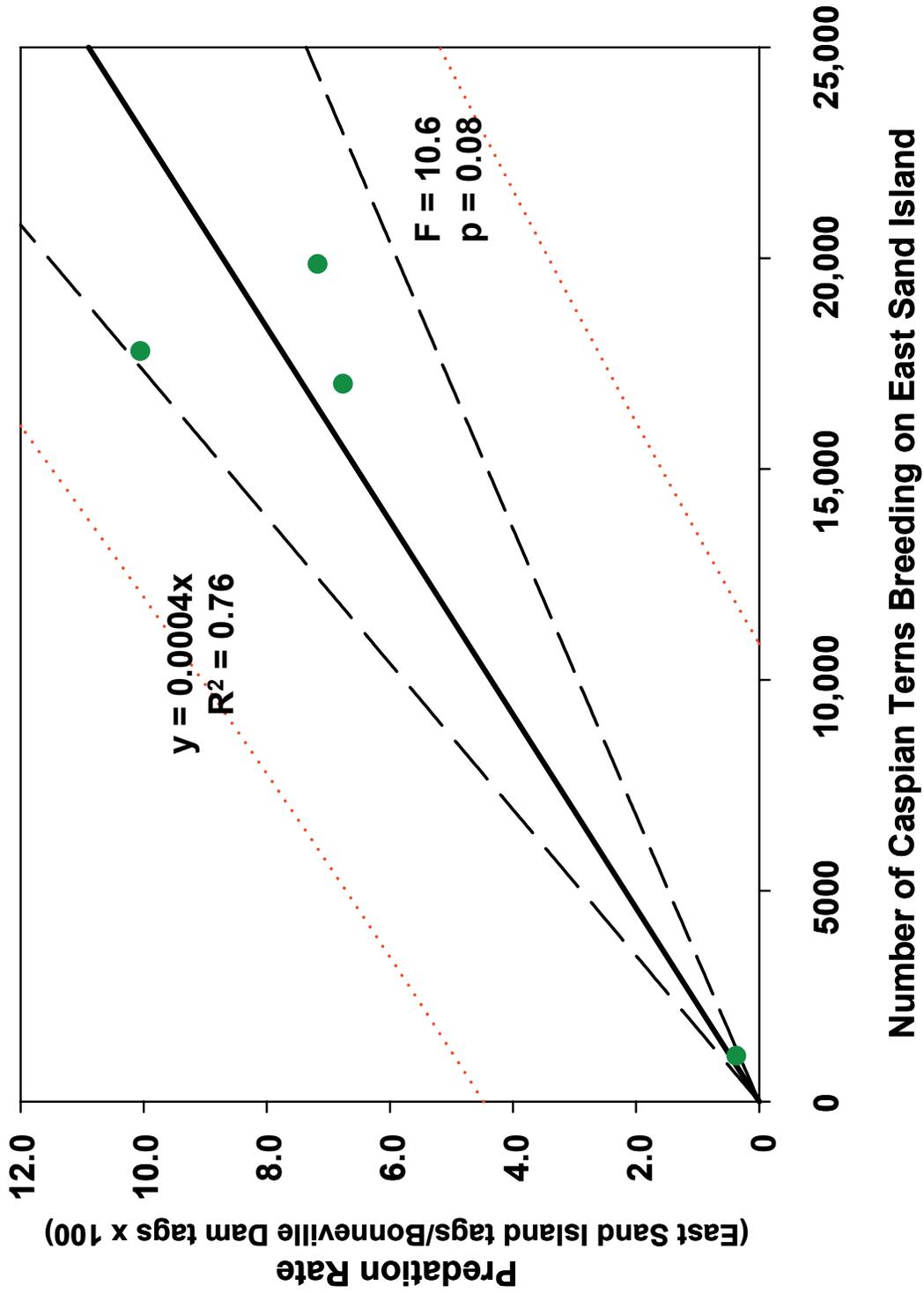


Figure 10. Linear regression of predation rates on the *Middle Columbia River steelhead ESU* in the Columbia River estuary by Caspian Terns breeding on East Sand Island (1999-2002) estimated using *recovery of PIT tags*. Dashed black lines represent 95% confidence limits; dotted red lines represent 95% prediction limits.