Fall 2010

Impacts of Avian Predation on Juvenile Salmonids in Central California Watersheds

Danielle Frechette
San Jose State University

IMPACTS OF AVIAN PREDATION ON JUVENILE SALMONIDS IN CENTRAL CALIFORNIA WATERSHEDS

A Thesis

Presented to

The Faculty of Moss Landing Marine Laboratories

San José State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Danielle Frechette

December 2010

The Designated Thesis Committee Approves the Thesis Titled

IMPACTS OF AVIAN PREDATION ON JUVENILE SALMONIDS IN CENTRAL CALIFORNIA WATERSHEDS

by

Danielle Frechette

APPROVED FOR MOSS LANDING MARINE LABORATORIES

SAN JOSÉ STATE UNIVERSITY

December 2010

Dr. James T. Harvey	Moss Landing Marine Laboratories
Dr. Michael H. Graham	Moss Landing Marine Laboratories
Dr. Sean A. Hayes	NOAA Fisheries
Dr. Leslee Parr	San Jose State University
Dr. Scott A. Shaffer	San Jose State University

ABSTRACT

IMPACTS OF AVIAN PREDATION ON JUVENILE SALMONIDS IN CENTRAL CALIFORNIA WATERSHEDS

by Danielle Frechette

Central California coho salmon (*Oncorhynchus kisutch*) are endangered and steelhead (*O. mykiss*) are threatened under the U.S. Endangered Species Act. As part of local monitoring efforts, Passive Integrated Transponders (PIT tags) are used in population biology and marine survival studies of these stocks. Since 2006, PIT tags have been recovered on Año Nuevo Island (ANI), an important breeding site for several species of seabirds and marine mammals. The objective of this study was to assess magnitude and effects of avian predation on juvenile salmonids in central California. Objectives were accomplished by 1) identifying predators, timing of predation, and quantifying predation using PIT tag recoveries and Mark-Recapture modeling, and 2) using behavior of a predator (the Western Gull) to examine susceptibility of juvenile salmonids to predation. Between 2006 and 2010, 252 unique PIT tags were recovered on ANI in areas that indicate Western Gulls were the primary predator depositing tags on ANI. Predation by gulls occurred during downstream migration of juvenile salmonids or immediately following ocean entry. Mark-Recapture modeling indicated PIT tags from 1-4% of tagged salmonids were deposited on ANI from watersheds in central California. Minimal temporal overlap between gulls and salmonids occurred at area watersheds, and observation of predation was rare; however, predation was 100% when overlap occurred. Predation by Western Gulls was an appreciable source of mortality for central California salmonids and should be considered in future management plans for these species.

ACKNOWLEDGEMENTS

I would like to thank the following people for their contributions to the success of this project: the members of the Bird Predation Team (A. Osterback, S. Hayes, S. Shaffer, and J. Moore), P. Morris, G. Oliver, M. Pavelka, and C. Winchell. Site access and project support were provided by the National Fish and Wildlife Service, California State Parks, the University of California Reserve System, CalPoly Swanton Pacific Ranch, and Big Creek Lumber. The following people were especially helpful: S. Auten, B. Dietterick, M. Foxworthy, G. McChesney, and G. Strachen. Funding was provided by CA SeaGrant 082-FISH-N, CDF&G Fisheries Restoration Grant Program, Packard Foundation Travel Award, the Dr. Earl and Ethel M. Myers Oceanographic and Marine Biology Trust, and the International Women's Fishing Association, Signe Memorial, and Martha Johnson Scholarships. My five committee members all made unique contributions to this thesis, and I thank them for their insight and feedback. J. Harvey provided excellent advice and guidance throughout this process, and even put up with my New England sarcasm. Go Yankees!

It took an army of volunteers to capture nearly 160 gulls. There are too many to mention individually, but collectively they got up before dawn, sat for hours on a cold windy cliff, and stayed out far past midnight to catch, count, and track gulls. My friends at MLML and NOAA for made this journey a lot more fun. T. Suskiewicz, I truly appreciate your editing and graphical help, and your support and patience throughout this process. My family has provided laughs, love, and support throughout the years, and I could not have gotten here without them.

TABLE OF CONTENTS

LIST OF FIGURES

Chapter I:

Chapter 2:

LIST OF TABLES

Chapter I:

Chapter II:

INTRODUCTION

In the eastern Pacific, five recognized species of salmon (Chinook, *Oncorhynchus tshawytscha*; chum, *O. keta*; coho, *O. kisutch*; pink, *O. gorbuscha*; sockeye, *O. nerka*) comprise 52 genetically distinct populations, or Evolutionary Significant Units (ESUs; Waples 1991). Twenty-four of the 52 ESUs are listed as endangered or threatened under the US Endangered Species Act (Good et al. 2007). Populations of anadramous, naturally-spawning steelhead trout, *O. mykiss,* are managed as fifteen Distinct Population Segments (DPS) in Washington, Oregon, Idaho, and California. Under the US Endangered Species Act (ESA), nine DPSs are listed as threatened and two are listed as endangered (http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Steelhead/Index.cfm). Decreases in populations of these commercially and culturally valuable species largely are attributed to what have been termed the four-H's; over-Harvest due to commercial and recreational fishing, obstruction of migratory routes because of Hydroelectric power, Habitat degradation, and supplementation of depleted runs using Hatchery fish (Roby et al. 2003, Good et al. 2007). Other sources of mortality may limit recovery of depressed populations, including variation in ocean productivity, competition with non-native species, and predation (Anderson et al. 2004, Good et al. 2007).

As Pacific salmonids have undergone population decreases, many species of piscivorous birds and mammals have experienced population increases during recent decades because of protection afforded by the Migratory Bird Treaty Act of 1918 (MBTA; 16 U.S.C.703-712) and the Marine Mammal Protection Act of 1972. Salmonids

are eaten by piscivorous birds, fish, and mammals and are vulnerable to predation during all life history stages (Collis et al. 2001, Roby et al. 2003, Major et al. 2005, Parsons et al. 2005, Weise & Harvey 2005, Anderson et al. 2007, Good et al. 2007, Wright et al. 2007). Predation by birds and mammals has significantly affected some populations of *Oncorhynchus* species and has resulted in an effort to quantify predation of threatened and endangered salmonids (Collis et al. 2001, Major et al. 2005, Parsons et al. 2005, Weise & Harvey 2005, Anderson et al. 2007, Good et al. 2007).

The central California coastal coho salmon (CCC-coho) ESU is listed as endangered and the central California coastal steelhead (CCC-steelhead) DPS is listed as threatened by the ESA. To enhance understanding of the population biology and marine survival for CCC-coho and CCC-steelhead, the Southwest Fisheries Science Center (SWFSC) began a program to tag juvenile salmonids with Passive Integrated Transponders (PIT tags). These tags are small, relatively inexpensive, and capable of lasting indefinitely, as they do not require a battery for operation. Tags are programmed with individual codes, therefore, are useful in monitoring movements of individual fish (Castro-Santos et al. 1996). As of April 2010, greater that 33,000 PIT tags have been deployed in one watershed in San Mateo County and four watersheds in Santa Cruz County.

In 2006, a PIT tag from a juvenile steelhead tagged in Scott Creek (Santa Cruz County, CA) was found on Año Nuevo Island (ANI), an important breeding area for several species of seabirds and marine mammals. Detections of PIT tags on seabird colonies have been used to document and quantify predation of salmonids by piscivorous

birds in the Columbia River Basin (Collis et al. 2001, Ryan et al. 2001). Discovery of this tag encouraged efforts to quantify the number of PIT tags on ANI, because tags represent tagged juvenile salmonids eaten by piscivorous predators and subsequently deposited on the island via regurgitation or defecation. The predator possibly responsible for depositing PIT tags on ANI was the Western Gull, because the majority of tags were located in areas of ANI used by Western Gulls for breeding.

The objectives of Chapter I were to: 1) quantify predation of juvenile salmonids using PIT tag recoveries from ANI; 2) use mark-recapture modeling to create a correction factor to improve estimates of predation generated by PIT tag recoveries; 3) identify predators; and 4) identify timing and location of predation. The objectives of Chapter II were to: 1) locate additional roosting sites used by Western Gulls along the central California coast and scan for PIT tags to improve estimates of predation of juvenile salmonids from central California watersheds by Western Gulls; 2) determine gull presence, abundance, and document predation attempts by gulls at watersheds in central California; and 3) examine movements of adult Western Gulls in relation to stage of the breeding cycle, availability of juvenile salmonids as a source of prey, and alternative foraging sites.

Chapter I

Application of mark-recapture methods to assess impacts of avian predation on juvenile salmonids in central California

ABSTRACT

In central California, coho salmon (*Oncorhynchus kisutch*) are endangered and steelhead (*O. mykiss*) are threatened, under the U.S. Endangered Species Act. While commonly attributed to anthropogenic causes, the role of avian predation in limiting recovery of coho and steelhead in central California was overlooked until recently. Passive Integrated Transponders (PIT tags) are used to monitor population biology and marine survival of these fish species. Año Nuevo Island (ANI), a breeding site for several species of piscivorous seabirds, has been scanned for PIT tags since 2006. Tags were not removed from the island and were detected on subsequent trips, allowing calculation of tag abundance using mark-recapture methods. POPAN, a variation of the Jolly-Seber model, estimated abundance and net entry of tags on to ANI. Detections from scans conducted between 2006 and 2009 were incorporated into the model, producing a tag abundance estimate of 247 (SE = 9.9). Probability of tag detection was constant among years (p = 0.64, SE = 0.04) and used to correct the number of tags detected during Spring 2010 (n = 44) for those present, but missed, generating a corrected estimate of tag deposition for 2010 of 72 (95% CI 68-74). Entry of tags on ANI primarily occurred by deposition by Western Gulls (*Larus occidentalis*) through regurgitation, and predation occurred primarily during downstream migration or immediately following ocean entry. These estimates improve our understanding of the effect of predation on recovery of central California coho and steelhead, and indicate that avian predation may be a significant source of mortality for central California salmonids.

INTRODUCTION

Salmon and trout (*Oncorhynchus spp*.) are commercially valuable, have decreased in number throughout much of their range, and many runs are listed as threatened or endangered under the U.S. Endangered Species Act (Spence et al. 2005). Decreases are attributed to the four-H's; over-Harvest due to commercial and recreational fishing, obstruction of migratory routes because of Hydroelectric power, Habitat degradation, and supplementation of depleted runs using Hatchery fish (Collis et al. 2001, Good et al. 2007).

Watersheds in California, south of the Golden Gate (37° 02' N and 122° 13' W), provide spawning and rearing habitat for Coho salmon (*Oncorhynchus kisutch*) and steelhead (*O. mykiss*). The central California coastal coho salmon Evolutionary Significant Unit (CCC-coho ESU) is listed as endangered and the central California coastal steelhead Distinct Population Segment (CCC-steelhead DPS) is listed as threatened by the ESA. Diversion of water for human use and changes in ocean productivity are major reasons for the continued decrease of the CCC-coho ESU and the CCC-steelhead DPS (MacFarlane et al. 2008, Lindley et al. 2009). Other sources of mortality, however, may limit recovery of depleted populations, including competition with non-native species and predation (Ruggerone 1986, Good et al. 2007). Salmonids are eaten by piscivorous birds, fish, and mammals, and are vulnerable to predation during all life history stages (Collis et al. 2001, Collis et al. 2002, Roby et al. 2003, Major et al. 2005, Parsons et al. 2005, Weise & Harvey 2005, Anderson et al. 2007, Good et al. 2007, Wright et al. 2007). Quantifying the magnitude of predation and its effect on salmon

populations and demography, therefore, is a crucial step in understanding the role of predation in limiting recovery of salmonids in central California.

Predation of juvenile salmonids by piscivorous seabirds has been well documented in the waters of the Columbia River Basin (Ruggerone 1986, Collis et al. 2001, Collis et al. 2002, Roby et al. 2003, Major et al. 2005, Anderson et al. 2007, Good et al. 2007). Until recently, however, there were few studies of predation of salmonids by birds in central California. Recoveries of Passive Integrated Transponders from Año Nuevo Island (ANI), a seabird breeding colony located in San Mateo County, California (37º 6' N 122 º 20' W), indicated that predation by piscivorous birds may represent a significant source of mortality for coho salmon and steelhead in central California.

Passive Integrated Transponders (PIT tags) commonly are implanted into salmonids to monitor movement, growth, and survival of individuals (Castro-Santos et al. 1996). Tags are small, relatively inexpensive, and consist of a copper antenna coil, capacitor, and microchip programmed with a unique code encased in a glass capsule. An electromagnetic field induced by a detection antenna energizes the tag, causing the tag identity to be transmitted and read by the detection antenna, hereafter, referred to as a PIT tag antenna (Roussel et al. 2000). Since 2002, PIT tags have been used to enhance understanding of the population biology and marine survival of CCC-coho and CCC-steelhead in several watersheds in Santa Cruz and San Mateo Counties by researchers at the NOAA Southwest Fisheries Science Center (NOAA-SWFSC).

Because PIT tags do not require a battery, they are capable of operating for the lifetime of a tagged salmonid (Castro-Santos et al. 1996). Tags also are capable of

remaining functional through ingestion of a tagged fish by piscivorous birds and mammals and subsequent defecation or regurgitation at breeding or roosting sites. Detection of tags on seabird colonies have been used to document and quantify predation of salmonids by piscivorous birds in the Columbia River Basin (Collis et al. 2001, Ryan et al. 2001, Roby et al. 2003). In 2006, recovery of a PIT tag originally deployed in a steelhead at a Santa Cruz County watershed prompted researchers at the NOAA-SWFSC to scan ANI for PIT tags on an annual basis, allowing an estimate of juvenile salmonid predation by species of piscivorous birds and mammals that use ANI for breeding and roosting.

Recovery of PIT tags, however, only allows minimum estimates of predation because an unknown number of tags are deposited away from breeding and roosting areas, not all tags on a colony are detected, and some tags lose function after ingestion or deposition on the island (Collis et al. 2001, Ryan et al. 2001). Improving estimates of predation of juvenile coho and steelhead will help us understand the role of predation in regulating populations of coho and steelhead in central California.

To improve our minimum estimate of predation of juvenile salmonids in five watersheds in San Mateo and Santa Cruz counties, I applied a novel use of mark-recapture statistics, which commonly are used to generate estimates of population parameters including survival (Lebreton et al. 1992), abundance (Jolly 1965, Seber 1965), and rate of population change (Pradel 1996). I chose to use the POPAN (Schwarz and Arnason 1996) formulation of the Jolly-Seber mark-recapture model because it allowed estimation of survival and capture rates, abundance, and rate of entry into an

open population (Schwartz and Arnason 1996, Arnason and Schwartz 1999). The PIT tags on ANI represent a distinct, open population of individual fish that were eaten by predators and deposited on the island through regurgitation or defecation, and may be lost from the island through erosional processes, tag breakage and loss of tag function, tag interference, and burial out of range of scanning antennas used for detecting tags (Collis et al. 2001, Ryan et al. 2001). Because PIT tags were individually marked, were not removed from ANI after detection, and often were detected during subsequent trips to the island, it was possible to use mark-recapture statistics to estimate population parameters associated with the population of tags (representing the number of salmonids eaten and deposited by predators) on ANI.

METHODS

Año Nuevo Island is a 10 hectare island located 1.6 km off Point Año Nuevo, San Mateo County, California. The island is owned and operated by California State Parks as part of the ~1617 hectare Año Nuevo State Reserve, and is accessible only to permitted researchers. The island provides breeding and roosting habitat for several species of piscivorous seabirds (Thayer & Sydeman 2004). Birds using ANI include Western and Heerman's Gulls (*Larus occidentalis* and *L. heermani*), two species of cormorants (*Phalacrocorax penicillatus* and *P. pelagicus*), Pigeon Guillimots (*Cepphus columba*), Rhinocerous Auklets (*Cerorhinca monocerata),* and Brown Pelicans (*Pelicanus occidentalis*). The island also provides breeding and resting habitat for

California sea lions (*Zalophus californianus*), Steller sea lions (*Eumetopias jubatus*), and northern elephant seals (*Mirounga angustirostris*).

Beginning in 2006, ANI was scanned for PIT tags annually. Limited time was spent on the island during each trip, therefore, greater than one trip was required to complete a full scan of the island (Table 1). Access to the island was granted through the University of California Natural Reserve System and California State Parks.

Table 1: Date of trips made to Año Nuevo Island to scan for PIT tags (2006 to 2010)

Season scan completed	**Date of trips**
Fall 2006	11/16/2006
	1/24/2007
Fall 2007	9/24/2007
Fall 2008	9/10/2008
	10/7/2008
	10/27/2008
	11/17/2008
	12/29/2008
Spring 2009	4/21/2009
	5/1/2009
Fall 2009	11/23/2009
	12/29/2009
Spring 2010	3/22/2010
	4/14/2010
	4/28/2010

A portable PIT tag antenna system, modified from the instream PIT tag reader system described by Bond et al. (2007) was used to scan the island for PIT tags (Fig. 1). The system was capable of detecting 134.2 kHz Full Duplex PIT tags and Half Duplex PIT tags, both of which were deployed in salmonids (Bond et al. 2007). The portable, pole-mounted circular antenna uses Allflex-USA, Inc. (Dallas–Fort Worth Airport, Texas) technology to run the antenna and communicate tag identities to a data logger (Bond et al. 2007). The system was powered by a 6-volt battery, carried in a backpack along with the data logger. Tag identity and time detected were logged for each tag.

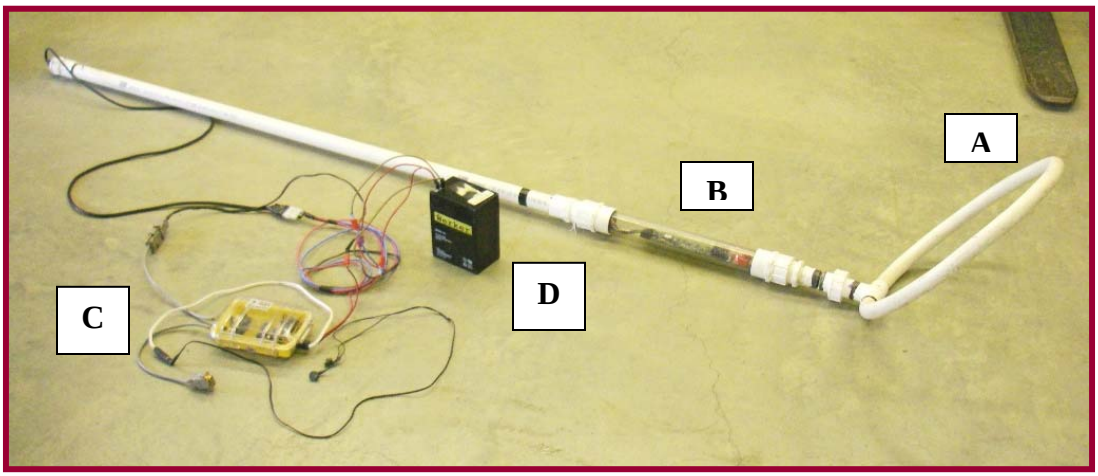

Figure 1: PIT Tag antenna system used to scan Año Nuevo Island. A) Circular antenna; B) Reader board (Allflex-USA, Inc. , Dallas-Fort Worth Airport, TX); C) Data logger; D) 6-volt battery

A portable GPS unit was carried during scans of the island beginning in 2007, allowing a GPS coordinate to be assigned for each tag detected. The GPS unit was set to log a GPS position at half-second intervals, providing a map of the land area covered on each survey, which was used to ensure that coverage of the island was adequate and

consistent among surveys. Tags first detected in 2006 were assigned a GPS location if they were detected during subsequent years. A database held by the NOAA SWFSC in Santa Cruz, California was used to determine the deployment history of each PIT tag detected on ANI. Using the database, it was possible to determine species, date, and location of initial tagging, subsequent dates fish were handled (for all watersheds), and any detections of fish by instream PIT tag antennas (Scott Creek only).

Data from PIT tag detections were analyzed using the Jolly-Seber model POPAN (Schwarz and Arnason 1996) within the framework of Program MARK v. 5.1 (White & Burnham 1999) to generate estimates of four parameters: 1) survival (Φ), interpreted as the probability that a tag was not lost from ANI, 2) probability of capture (p), interpreted as the probability of detecting a given tag during a complete scan of the island, given that the tag was in the population and available to be detected, 3) the probability of entering the population (β) through defecation or regurgitation, and 4) population size (N). From these four parameters, two additional parameters were derived within POPAN: 1) estimates of net births $(\hat{B})$, interpreted as the number of tags entering the population in a given year, and 2) population abundance $(\hat{N})$. The probability of tags being lost from the population was calculated as (1- Φ). A candidate set of four models was created in which the survival (Φ) and capture (p) parameters were either held constant (·) or allowed to vary annually (t). The probability of entry (β) was always allowed to vary with time, because the number of tags deployed in juvenile salmonids in watersheds within San Mateo and Santa Cruz counties varied considerably by year (Table 2). When fitting the candidate models, the logit link function was used for the parameters Φ and p and the log

link function was used for the parameter $\hat{N}$. The set of β parameters must sum to ≤ 1, so the multinomial logit link function was used to constrain the β parameters to facilitate convergence (Schwarz & Anderson 1996, White & Burnham 1999).

Table 2: Number of PIT tags deployed in each watershed during each year and distance from ANI

Watershed	Distance from ANI (km)	Year	# tags deployed
Gazos (SMC)	6.6	2003	150
		2004	289
		2005	323
		Total	**762**
Waddell (SCC)	5.5	2006	159
		2008	720
		2009	697
		Total	**1576**
Scott (SCC)	12.0	2003	2263
		2004	2359
		2005	1512
		2006	3585
		2007	2807
		2008	3877
		2009	7173
		2010	3403
		Total	**26979**
San Lorenzo (SCC)	33.0	2004	140
		2005	261
		Total	**401**
Soquel (SCC)	38.0	2003	228
		2004	438
		2005	963
		2006	871
		2007	617
		2008	227
		2009	311
		2010	22
		Total	**3677**
Aptos (SCC)	41.0	2004	342
		2005	171
		Total	**513**
Total # of tags deployed			**33908**

Models were compared using Akaike's Information Criterion, adjusted for small sample sizes (AICc), with the model that best fit the data (i.e. explained the greatest amount of variance within the data) receiving the lowest AICc value. The relative fit of models in the candidate model set was assessed by comparing AIC weights (Burnham & Anderson 2002).

During 2009 and 2010, it was possible to access ANI during the spring (at the start of the breeding season of Western Gulls), and the autumn (post-breeding period). Data from scans conducted during spring 2009, autumn 2009, and spring 2010 were used to determine timing and location of predation by comparing the date a fish was last known alive with the first known detection on ANI. The date a fish was last known alive was determined based on 1) the last date a fish was handled alive, or 2) detections of fish by instream PIT tag antennas in Scott Creek.

RESULTS

Complete scans of the island were conducted during autumn 2006, 2007, 2008, spring 2009, and autumn 2009. An additional scan was completed during spring 2010, however, the area scanned was not comparable with area covered during previous scans of the island due to disturbance related access restrictions. Data from spring 2010 were not included in the estimation of tag abundance using POPAN, as a critical assumption of this model was that the study area does not change in size during the course of the study (as this can under- or overestimate abundance and associated parameters, Arnason & Schwarz 2002). Data from Spring 2010 were analyzed with data collected during scans

in spring and autumn 2009 to determine the seasonality of predation of tagged fish and subsequent deposition on ANI.

In total, 252 PIT tags were detected on Año Nuevo Island (Fig. 2), representing wild and hatchery coho and steelhead tagged in four watersheds in Santa Cruz County (Waddell, Scott, Soquel, and San Lorenzo) and one watershed in San Mateo County (Gazos). It was possible to determine the identity of 247 of the tags detected using the database held by NOAA-SWFSC in Santa Cruz (Table 3).

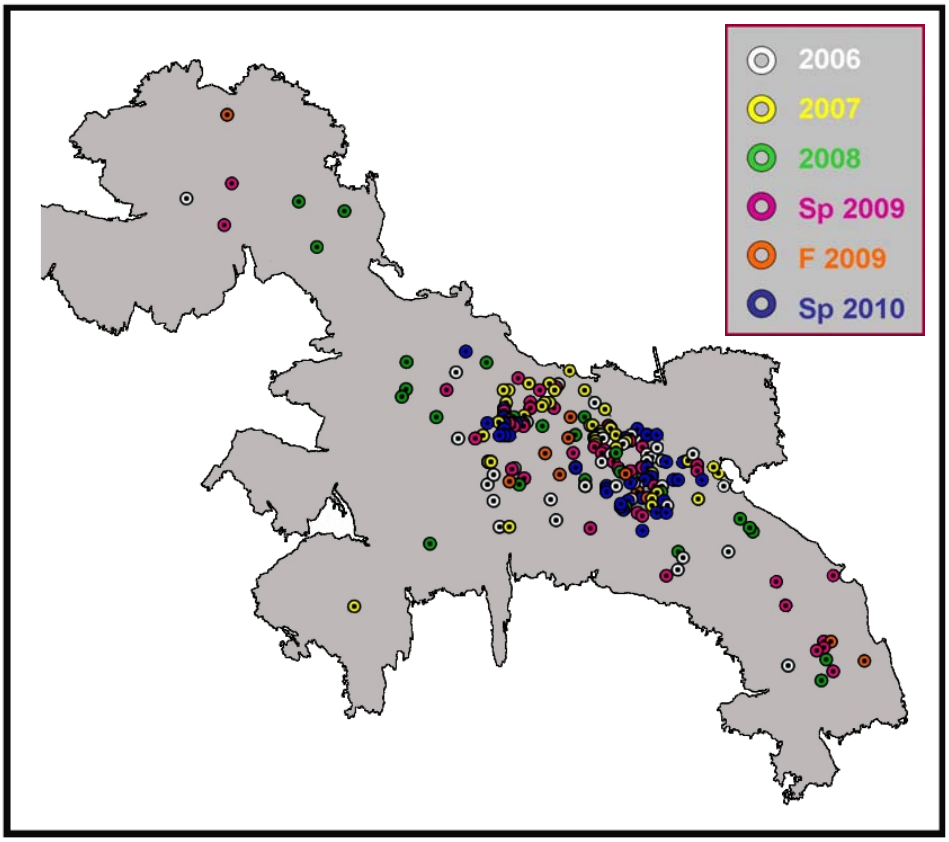

Figure 2: Location of PIT tags on ANI, by year of detection. Grey denotes the island, surrounding water is white, circles represent tag locations. Colors correspond to the year a tag was first detected (white = 2006, yellow = 2007, green = 2008, pink = Spring 2009,orange = Autumn 2009, blue = Spring 2010)

Table 3: PIT tags detected on Año Nuevo Island by location of tagging (watershed, species, and year first detected) between 2006 and 2010. Not included are two PIT tags removed from ANI during June 2006 (1 coho, 1 steelhead, both from Scott Creek) before the start of annual surveys

	Waddell: Steelhead	Gazos: Steelhead	Scott: Coho	Scott: Steelhead	Scott: Unknown Sp.	San Lorenzo: Steelhead	Soquel: Steelhead	Unidentified Tags	Total detected per year
Year first detected	Number of Fish Detected on ANI								
2006	2	12	8	17	0	0	0	0	39
2007	6	5	16	42	1	1	2	0	73
2008	6	2	4	19	0	0	0	2	33
2009 (Spring)	12	0	4	32	0	0	1	2	51
2009 (Fall)	4	0	2	6	0	0	0	0	12
2010	24	0	0	20	0	0	0	0	44
Total	54	19	34	136	1	1	3	4	252

Tag detections (total detections: N = 425, Unique tags: N = 208) from scans completed during Autumn 2006, 2007, 2008, Spring 2009, and Autumn 2009 were incorporated into the POPAN model (Schwarz and Arnason 1996). The AICc values associated with three of the four models were essentially indistinguishable; the fourth model was classified as different from these three models, but did not provide a good fit for the data (Program RELEASE Goodness of Fit, $\chi^2 = 0.01$). When all data from 2006 to Fall 2009 was included in the POPAN analysis, therefore, it was not possible to select any of the four models in the candidate model set as being the most parsimonious (Table 4). During Autumn 2009, approximately half of the tag population was lost from ANI, likely because of a large rainfall event which occurred during early October, 2009, before the island was scanned for PIT tags during November of 2009. The inability to distinguish one model as best-fitting the data probably was caused by the loss of such a large proportion of the tags from ANI between Spring and Autumn of 2009.

Table 4: Comparison of candidate POPAN models used to estimate abundance, survival, recapture, and entry parameters (2006 - Fall 2009).
AICc = Akaike's Information Criterion adjusted for small sample sizes, Delta AICc = difference in AICc between the AICc for a given model and the AICc for the best-fit model, AICc Weight = Akaike weight indicating the relative support for a model, based on AICc, Φ = probability of survival, p = capture probability, β = probability of entry

Model ID	Model	AICc	Δ AICc	AICc Weights	No. of Parameters
A	Φ(.)p(.)b(t)	679.5091	0.0000	0.4332	14
B	Φ(t)p(.)b(t)	680.1281	0.6190	0.3179	11
C	Φ(.)p(t)b(t)	680.6169	1.1078	0.2490	10
D	Φ(t)p(t)b(t)	703.2706	23.7615	0.0000	7

Because it was not possible to select a model that best fit the data when all data from 2006 to Autumn 2009 were incorporated into the POPAN model, I re-ran the analysis excluding data from Autumn 2009. This new analysis incorporated tag detections (total detections: N = 358, Unique tags: N = 196) from scans completed during Autumn 2006, 2007, 2008, and Spring 2009 into the POPAN model (Schwarz and Arnason 1996).

When Autumn 2009 was excluded from analysis, the model which best fit the data (received the least AICc score), was a model in which probability of survival and probability of capture were constant, and the probability of entry varied with time (Table 5, Model A). Based on a comparison of the AICc weights, support for this model was 3.6 times greater than the next best model (Table 5, Model B). Probability of survival was an estimated 0.8578 (95% CI 0.7644 to 0.9188; Table 6), and probability of capture was 0.6436 (95% CI 0.5547 to 0.7237; Table 6). The tag population on the island increased each year (Table 7), with the greatest percentage of tags (25.6%) arriving on the island between 2008 and 2009 (Table 6, $\beta 3$). The population of tags on the island before the first survey was estimated to be 92 individuals (95% CI 68.0 to 115.2; Table 7). The super population size predicted by the best fit model was 242 PIT tags (95% CI 222.8 to 261.2; Table 7).

Table 5: Comparison of candidate POPAN models used to generate estimate abundance, survival, recapture, and entry parameters (2006 - Spring 2009). AICc = Akaike's Information Criterion adjusted for small sample sizes, Delta AICc = difference in AICc between the AICc for a given model and the AICc for the best-fit model, AICc Weight = Akaike weight indicating the relative support for a model, based on AICc, Φ = probability of survival, p = capture probability, β = probability of entry

Model ID	Model	AICc	Δ AICc	AICc Weights	No. of Parameters
A	Φ(.)p(.)b(t)	458.7378	0.0000	0.6730	6
B	Φ(t)p(.)b(t)	460.9820	2.2442	0.2191	8
C	Φ(.)p(t)b(t)	462.7908	4.0530	0.0887	9
D	Φ(t)p(t)b(t)	465.8586	7.1208	0.0191	11

Table 6. Estimates of real parameters from the best fit model [Φ(.)p(.)β (t)]. Φ = probability of survival, p = capture probability, β= probability of entry. Estimates for each parameter is presented with associated standard errors (SE) and upper and lower 95% confidence intervals (CI)

Parameter	Parameter Estimate	SE	Lower 95% CI	Upper 95% CI
Φ	0.8578	0.0386	0.7645	0.9181
p	0.6436	0.0435	0.5547	0.7237
β1	0.2327	0.0494	0.1499	0.3427
β2	0.1185	0.0424	0.0572	0.2297
β3	0.2562	0.0419	0.1830	0.3464

Table 7. Estimates of derived parameters from the best fit model [Φ(t)p(.)β(t)]. Net Births = # of tags arriving on the island between each pair of years, Population estimates = # of tags in the island population in each year ANI was scanned for PIT tags, Super Population Size = # of tags in the ANI tag population across all four years of the study. Estimates for each parameter is presented with associated standard errors (SE) and upper and lower 95% confidence intervals (CI).

Parameter	Parameter Estimate	SE	Lower 95% CI	Upper 95% CI
Net Births				
2006-2007	58.5	12.5	34.1	83.0
2007-2008	29.8	10.6	9.0	50.7
2008-Spring 2009	62.1	11.2	40.2	84.0
Population Estimates				
2006	91.6	12.0	68.0	115.2
2007	132.8	12.1	109.1	156.5
2008	141.6	11.8	118.5	164.7
Spring 2009	190.9	13.9	163.7	218.2
Super Population Size	242.1	9.8	222.8	261.3

Using the best-fit model described previously, it was possible to create a correction factor to apply to future scans of ANI to determine the number of tags that were on the island, but were missed. The best-fit model predicted that the probability of detecting a tag during a scan of the island was constant among years (capture probability, $p = 0.64$). This constant probability of detecting a tag and associated 95% confidence intervals were used to predict the number of tags that were on the island, but missed, during scans of the island completed during Autumn 2009 and Spring 2010 (Table 8, B). Multiplying the probability of tag detection by the number of tags detected indicated that an additional 8 tags were deposited on the island between Spring and Fall 2009 (95% CI

7 to 9 tags; Table 8B) and 28 tags were deposited on ANI between December 2009 and March 2010 (95% CI 24 to 31 tags; Table 8B), but were not detected in the area scanned during surveys completed during Autumn 2009 and Spring 2010. Application of this correction factor increased the estimate of tags deposited on the island to 20 (Autumn 2009 Table 8C) and 72 (Spring 2010, Table 8C). Adding the corrected number of tags detected during Autumn 2009 and Spring 2010 to the estimated tag population calculated using the best-fit POPAN model for the period from 2006 to Spring 2009 (242 tags), produced a corrected estimate of 334 tags. Thus, 334 tags are estimated to have been deposited on the island between 2006 and Spring 2010, an increase of 82 tags compared with the 252 tags that actually were detected on the ANI.

The number of tags detected on ANI (2006 to Spring 2010) from fish tagged in Scott Creek (n = 171) was 2.1 times greater than the number of tags recovered from the remaining 4 watersheds (n = 53). It was not possible, therefore, to run the POPAN model with the data grouped by watershed. To apply a corrected minimum estimate of predation to each watershed, I took the percentage of tags detected on the island for each watershed (Table 9A, and multiplied it by the new corrected estimate of tag deposition (334 tags). By applying this correction, there was no increase in the number of tags originating from San Lorenzo and Soquel Creek in the ANI tag population (Table 9B). New estimates of tags originating from Scott Creek (227), Gazos Creek (25), and Waddell Creek (72) were obtained when the correction was applied, increasing the minimum predation rates for these watersheds to 0.85% for Scott Creek, 3.3% for Gazos Creek, and nearly 4.5% for Waddell Creek (Table 9B).

Table 8: Corrected tag deposition estimates for Autumn 2009 and Spring 2010. A) recapture probability from the best-fit model [Φ(t)p(.)β(t)], B) estimated number of tags missed, C) corrected estimate of tags deposited on ANI

		Estimate	Lower 95% CI	Upper 95% CI
A.	Recapture probability (p)	0.64	0.60	0.75
B.	Estimated # of tags missed (Autumn 2009)	7.68	4.60	3.46
	Estimated # of tags missed (Spring 2010)	28.16	26.33	33.08
C.	Corrected tag estimate (Autumn 2009)	19.68	16.60	15.46
	Corrected tag estimate (Spring 2010)	72.16	70.33	77.08

Table 9. Corrected estimates of tags deposited on ANI by watershed of origin. A) Number of tags recovered on ANI from five central California watersheds between 2006 and Spring 2009 that were included in the MARK model, presented as 1) total number and 2) percentage of total number of tags detected on ANI, 3) the number of tags deployed per watershed and 4) the percentage of tags recovered on ANI relative to the number deployed in each watershed. Corrected estimate of tags deposited on ANI by watershed of origin presented as 1) number of tags and 2) corrected percentage relative to number deployed in each watershed

		Watershed					
A.	N	Waddell	Gazos	Scott	San Lorenzo	Soquel	Unidentified
# of tags recovered on ANI	252	54	19	171	1	3	4
% of total recovered on ANI		21.43	7.54	67.86	0.40	1.19	1.6
# tags deployed	33908	1576	762	26979	401	3677	NA
Predation rate (% of tags deployed)		3.43	2.49	0.63	0.25	0.08	NA
B.							
Estimated # of tags recovered on ANI	334	71.57	25.18	226.64	1.33	3.98	NA
Estimated predation rate (% of tags deployed)		4.46	3.30	0.85	0.33	0.09	NA

The majority of tags detected (approximately 90%) on ANI were located in an area used by Western Gulls (*Larus occidentalis*) for breeding. Approximately 7% of tags were located in an area used by Brandt's Cormorants (*Phalacrocorax penicillatus*) for breeding (Pat Morris, pers comm.). The remaining 3% of tags were detected in an area used by Western Gulls and California Sea Lions (*Zalophus califonianus)*. Four tags were from steelhead that were last handled as adults (mean fork length 40.3 cm, SD = 2.4), indicating that these fish were likely eaten by pinnipeds, rather than birds because birds could not catch and consume such a large fish. Gulls could ingested PIT tags while scavenging a dead, PIT-tagged adult salmonid, however the probability of this occurring was believed to be extremely low, therefore, it was more likely that these tags were deposited on the island by California sea lions.

Between spring 2009 and spring 2010, 103 unique tags were detected for which the fish identity was known and were last handled as juveniles. These individuals were used to investigate timing and location of predation. Forty-nine tags from salmonids of known identity and last handled as juveniles were first detected during spring 2009 (Fig. 3). Twelve of these fish originated in Waddell Creek (all steelhead), the remainder (n = 37) were tagged in Scott Creek. Six fish that originated in Waddell Creek were detected on ANI > 1000 days after they were last handled alive, and 6 fish were detected on ANI between 150 and 250 days after they were last handled alive. Nine fish (1 coho, 8 steelhead) originating in Scott Creek were first detected on the island less than 90 days after the last date they were known alive, indicating that predation occurred between late autumn 2008 or winter/spring 2009, during downstream migration to the ocean. Two

steelhead first were detected on ANI 22 and 32 days after they were last detected alive, by a PIT tag antenna positioned in a 100-m stretch of Scott Creek where the creek crosses the beach before entering the ocean. A third steelhead was detected on ANI 11 days after it was last detected alive by a PIT tag antenna positioned approximately 1 km upstream of the creek mouth, indicating that predation occurred during April 2009.

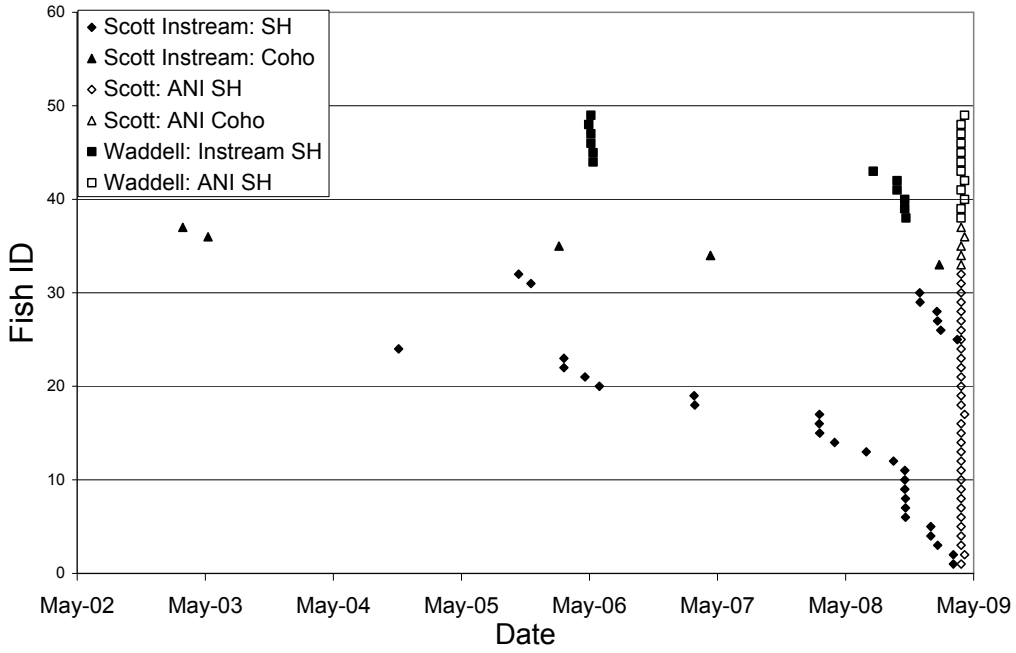

Figure 3. PIT tags from steelhead and coho detected on Año Nuevo Island during Spring 2009. Closed symbols denote the date fish were last instream. Open symbols denote the date fish were first detected on ANI. Symbol shape denotes watershed where fish were tagged. Fish ID # corresponds to a specific PIT tag number.

During autumn 2009, 12 new tags were detected on ANI (Fig. 4). One was not identifiable, and another was from an adult, so both were removed from the analysis of predation timing. Two of the remaining fish were steelhead tagged in Waddell Creek between August and October 2009, indicating that predation occurred during Autumn of

2009. One steelhead tagged in the Waddell Creek lagoon during October 2009 was detected on ANI 35 days later. The other two fish were handled alive in Waddell Creek 209 and 253 days before detection on ANI. Tags from five steelhead and two coho from Scott Creek were detected on ANI during autumn 2009. Three of the steelhead were last alive less than 300 days before first detection on ANI, whereas the remaining tags were from coho and steelhead last handled alive between 2003 and 2008 (Fig. 4). Because the probability of detecting a tag on the island was constant, the probability of missing a tag during a scan of the island also was constant (1-p = 0.3564).

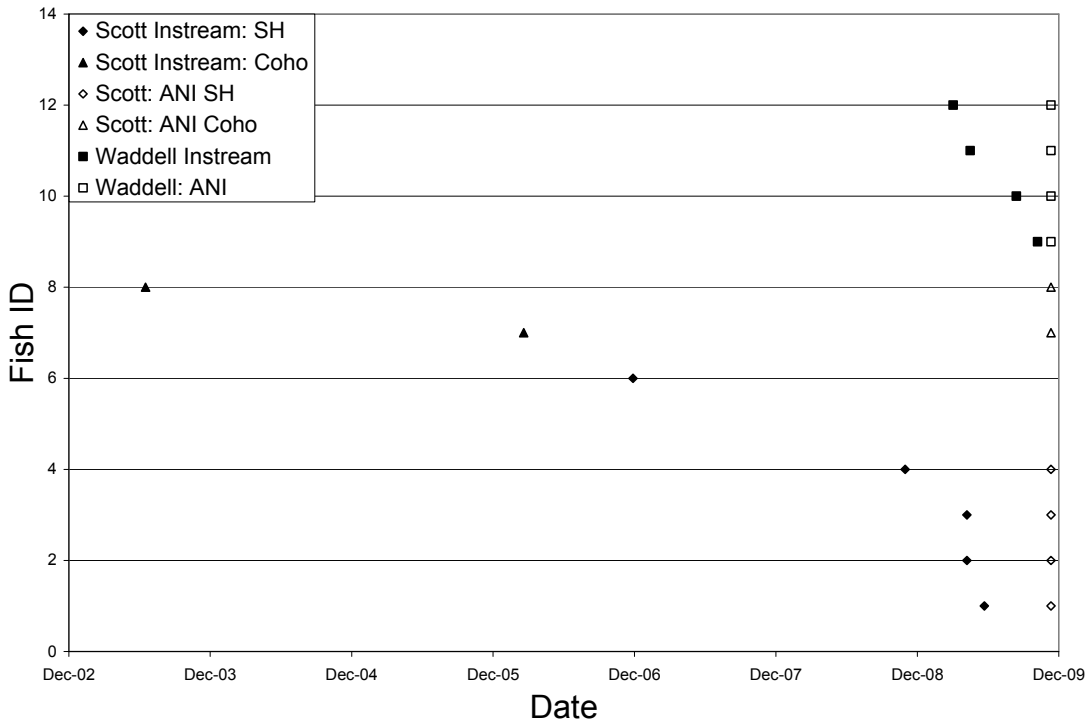

Figure 4. PIT tags from steelhead and coho detected on Año Nuevo Island during Autumn 2009. Closed symbols denote the date fish were last instream. Open symbols denote the date fish were first detected on ANI. Symbol shape denotes watershed where fish were tagged. Fish ID # corresponds to a specific PIT tag number

During spring 2010, 44 new tags were detected on ANI, 43 of which were identifiable; 46% originated in Scott Creek and 54% originated in Waddell Creek (Fig. 5). All tags detected during spring 2010 were from steelhead. Two tags from steelhead originating in Scott Creek were detected on ANI 501 and 519 days after they were last handled alive, and one steelhead was detected on ANI 1,869 days after it was last handled alive. Seventy-five percent of tags detected on ANI for the first time during spring 2010 were last alive ≤102 days before they were detected, indicating that predation primarily occurred during winter and spring of 2010. The remainder of Scott Creek fish detected on ANI during spring 2009 (n = 3) were detected less than 135 days after they were last alive. All tags originating from Waddell Creek were handled alive between April 30 and November 11, 2009 (average time elapsed between handling and detection was 213 days, SD = 76).

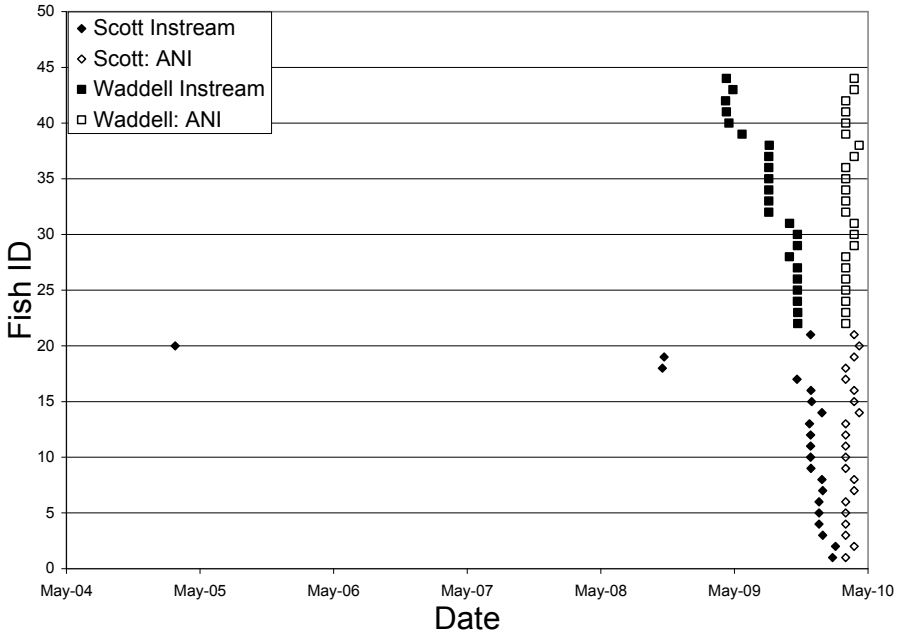

Figure 5. PIT tags from steelhead and coho detected on Año Nuevo Island during Spring 2010. Closed symbols denote the date fish were last instream. Open symbols denote the date fish were first detected on ANI. Symbol shape denotes watershed where fish were tagged. Fish ID # corresponds to a specific PIT tag number.

DISCUSSION

I applied a novel use for the POPAN variation (Schwarz & Arnason 1996) of the Jolly-Seber model (Jolly 1965, Seber 1965) to correct our minimum estimate of juvenile salmonids eaten by piscivorous predators and deposited on Año Nuevo Island. This estimate increases the minimum number of tags deposited on ANI between 2002 and autumn 2009 by 46 tags, relative to the 196 tags detected on the island during the four complete scans of the island. This means that an estimated 242 salmonids (*O. kisutch and O. mykiss*) tagged in Gazos, Waddell, Scott, San Lorenzo, and Soquel watersheds between 2003 and Spring 2009 were eaten by predators that subsequently travelled to and deposited the tags on ANI. Additionally, I was able to generate a correction factor using the constant probability of capture (Table 7A), which can be applied to future surveys of ANI to improve estimates of tag deposition rates. When the corrected estimate of 92 tags deposited on ANI between May 2009 and April 2010 was added to the super-population size of 242 tags generated by the POPAN model, the new minimum estimate of predation by predators using ANI was approximately 334 tagged salmonids.

Although it was not possible to directly measure efficiency of detecting tags, the constant probability of capture indicates that scanning effort and PIT tag antenna efficiency was consistent among all surveys. Tags may be lost from the population by four mechanisms: tags may 1) become buried too deep for detection by portable PIT tag scanning equipment, 2) be removed from the island due to erosion processes or weathering (wave or wind events), or 3) lose the ability to be detected through tag breakage, or 4) through tag interference: if one tag is deposited too close to another tag,

they may cancel each out, preventing detection of one or both tags (Collis et al. 2001, Ryan et al. 2003). Tag loss from the island was greatest between spring and autumn 2009. Despite consistent scanning between spring and autumn 2009, I only detected 56 previously detected tags on ANI during Autumn 2009, less than half the number of tags detected during Spring 2009 (n = 127 tags). Rainfall was minimal in central California between 2006 and 2009, however, during October 2009, greater than 25 cm of rain fell during a 24-hour period prior to our fall survey. The heavy rain event of October 2009 may have caused tags to be lost from the island at a greater rate that previously observed. Additionally, dry conditions that occurred from 2006 to Spring 2009 may have allowed tags to remain on the island longer than they would during wetter years.

The variation among years in probability of entry, as predicted by the best-fit model, reflects the *a priori* expectation that variation in tags arriving on the island would reflect the variability in number of tags deployed in juvenile salmonids by year. There were 27,670 PIT tags deployed in juvenile salmonids in five central California watersheds between 2003 and 2009. During 2008 and 2009, the number of PIT tags deployed in juvenile salmonids was greatly increased as part of a study to understand the effects of predation on juvenile salmonids, which is reflected in the increased percentage of tags arriving on the island between 2008 and 2009. Of the total number of PIT tags deployed, 17.6% were deployed during 2008, and 27.4% were deployed during 2009; in comparison, less than 14% were deployed in each of the other 5 years of the study. The probability of entering the population of tags on ANI was greater between 2006 and 2007 than between 2007 and 2008. The percent of tags deployed during 2007, however, did

not decrease relative to the tags deployed during 2005 or 2006. Between 2003 and 2006 a subset of hatchery and wild salmonids (coho and steelhead) in Scott Creek was tagged with temperature loggers in addition to PIT tags (Hayes et al. in press). Of the tags detected for the first time on ANI during 2006, 15.25% were fish tagged with temperature loggers during 2006. During 2007, 5.66% of the new tags detected were from fish with temperature loggers. Fish with temperature loggers accounted for 2.94% of new tags detected during 2008 and 2.00% of new tags detected during 2009. These results indicate that temperature loggers likely increased susceptibility of juvenile coho and steelhead to predation, which is reflected in the greater percentage of fish that arrived on the island between 2006 and 2007 (when the majority of these fish would have been susceptible to predation), relative to the percentage that arrived on the island between 2007 and 2008.

Examination of PIT tag recoveries from ANI during spring 2009 indicated that the majority of tagged salmonids were eaten by predators using ANI during the downstream migration of fish to the ocean, or immediately following ocean entry. During the scan of ANI completed during spring 2009, 18.75% of new tags detected on the island (tags which had not previously been detected, n = 48) were from steelhead handled or detected by PIT tag antennas (Scott Creek only) during winter and spring 2009. Although 52% of the salmonids (all steelhead) first detected during spring 2009 were last alive during 2008, it is likely that these fish also were eaten during downstream migration or following initial ocean entry during 2009. Whereas coho generally migrate directly to sea after smoltification, steelhead in central California watersheds have alternative life history strategies and may either migrate to sea, or over-summer in the estuarine portion

of the watershed for several months (Bond et al. 2008,) before migrating back upstream for the winter and performing a second downstream migration the following spring, ultimately entering the ocean a year later. (Hayes et al. in review).

Generally between November and January, greater flows associated with winter rains break open the sandbars and open the estuary to the sea, which allows adult salmon access to spawning territory and allows smolt access to the ocean (Shapovalov and Taft 1954, Hayes et al. 2004). Downstream movement of juvenile coho and steelhead was observed during this period. The majority of downstream migration of steelhead occured between February and June. Fish migrating earlier (February to March) were significantly larger than fish migrating later (April through June) (Shapavalov and Taft 1954, Hayes et al. in review). Smaller fish migrating later probably were travelling downstream to lagoon habitat to take advantage of greater food availability and associated increased growth rates, whereas larger fish migrating earlier were considered to be on their way to the ocean, having foraged in the lagoon the previous summer (Hayes et al. in review).

The majority of PIT tags from fish handled in 2008, which were detected first on ANI during spring 2009, likely represent steelhead that were tagged during 2008, spent summer in the lagoon, and were eaten by predators on their way to the ocean or immediately following ocean entry during spring 2009. Only four (23%) steelhead detected on ANI during Spring 2010 were tagged in Scott Creek before sandbar formation in 2008, whereas the remaining 76% were tagged in the Scott Creek lagoon between July and November 2008. Detections of fish tagged in the lagoon between July

and November 2008 by instream PIT tag antennas after bar breakage in December 2008 provide further support that these fish moved out of the Scott Creek watershed as downstream migrants during 2009. All steelhead tagged in Waddell Creek during 2008 that were first detected on ANI in 2009 were tagged after April 24, 2008. Only three fish were tagged before bar formation, and had an average fork length of 120.67 mm (SD = 8.62). These fish likely recruited to the Waddell Creek lagoon, and were eaten by predators during downstream migration or shortly after ocean entry in 2009 (Hayes et al. in press).

Tags detected on ANI during autumn of 2008 and 2009 indicate that predation of juvenile salmonids by Western Gulls using ANI also may be occurring in the Waddell Creek lagoon, but not the Scott Creek lagoon, during the late summer and autumn. Six tags were detected on ANI during scans conducted during autumn, which were from steelhead tagged in the Waddell Creek lagoon between August and November. In contrast, no tags deployed in the Scott Creek lagoon during summer and autumn were detected on ANI during surveys of the island conducted during autumn. The lagoon dynamics of these two systems differ, with Scott Creek generally remaining closed until the first winter storm, however, Waddell Creek has a more dynamic mouth and opened and closed multiple times during autumn of 2008 and 2009. Because lagoon dynamics differ, it follows that predation dynamics also probably differ between the two watersheds.

During 2009, eight tags were detected that were from fish alive before 2008. These tags could have one of the following histories: 1) the fish carrying the tags were

eaten as juveniles, during downstream migration or early ocean entry and deposited on the island during the year they were last detected alive but missed on previous trips to the island, 2) the fish remained in the watershed for some time after the last known detection, were missed by instream PIT tag antennas (which operate with less than 100% efficiency), were eaten as juveniles, and were deposited on the island after the year in which they were last detected alive, or 3) the fish were eaten as adults returning to natal streams to spawn. Four tags from steelhead were detected on the island between autumn 2006 and autumn 2009 that were adults the last time they were handled alive. The only predators, which use elevated portions of ANI that were scanned for PIT tags and is large enough to catch an adult steelhead, are California Sea Lions (*Zalophus californianus).*

The probability of missing one tag, as predicted by the POPAN model was constant (0.36) among years. It was possible, therefore, to predict the probability that a tag had been on the island during all surveys between the date the fish was last known alive and the survey in 2009 when it was first detected on ANI. Two tags were from juvenile fish last handled alive during 2007. One tag was from a coho (FL = 109 mm) and the other tag from a steelhead (FL = 153 mm). There was a 4.7% chance that these tags were on the island during surveys in 2007 and 2008 and were missed. One coho (FL = 235 mm from Scott Creek) and one steelhead (FL = 118 mm, from Waddell Creek) last handled alive during 2006 were first detected on the island in 2009. There was a 1.7% chance that these fish were on the island during scans competed in 2006, 2007, and 2008 before being detected in 2009. It also is possible that all four of these fish were eaten as adults by California sea lions during return migrations to Scott Creek (coho) and Waddell

Creek (steelhead) in 2009, therefore, were first available to be detected during 2009. Three tags from steelhead that were last handled alive (as juveniles) during 2005 were first detected on ANI during spring 2009. There was a 1.7% chance that these fish were on the island during scans competed in 2006, 2007, and 2008 before being detected in 2009, however, because steelhead are iteroparous, these fish could have been eaten by California sea lions pre- or post-spawning either on their first return trip to natal streams (Scott and Waddell Creeks), or during subsequent spawning returns. Because the probability of missing each of these seven tags during multiple surveys was low (<5%), it is likely that these tags represent adult salmonids that were captured and eaten by California seal lions either on return migrations to natal streams (coho and steelhead) or post-spawning (steelhead).

Although tag recoveries indicate a low level of predation of adult salmonids by California sea lions, there is considerable support that the majority of tags that arrived on ANI during the course of this study were from fish eaten by Western Gulls. No predators that visit ANI have been observed upstream of the bridges that cross Scott and Waddell Creeks, approximately 100 to 200 m from where these creeks enter the ocean (Chapter 2). The only predator observed on the beach at Scott Creek and on ANI was the Western Gull. This is the only species that has been visually documented eating juvenile salmonids in watersheds in Santa Cruz County. During Spring 2008, visual observations were conducted at the mouth of Scott and Waddell Creeks to document predation of juvenile salmonids (Chapter 2). In 198 hours of observation, 20 predation events were recorded. The Scott Creek mouth was generally shallow (less than 30 cm deep) and clear,

which allowed observers to see fish as they swam downstream towards the ocean. During a three-hour period in April 2008, 20 juvenile salmonids were observed migrating downstream, across the Scott Creek beach. All 20 fish subsequently were captured by Western Gulls (Chapter 2). Adult and juvenile Western Gulls caught and ate free-swimming salmonids with equal efficiency (Chapter 2). Additional support for predation of juvenile salmonids by Western Gulls comes from two temperature loggers that were deployed in Scott Creek (one in a coho, and one in a steelhead) and subsequently recovered on ANI (Hayes et al. in press). The temperature record from each tag indicated several weeks of temperatures which corresponded with those of the estuary, followed by a dramatic increase in temperature at the time of predation, indicating that predation occurred in the watershed before ocean entry (Hayes et al. in press).

Locations of tag detections provide further support for Western Gulls being the primary predator bringing tags from juvenile salmonids to ANI. The majority of tags were located in the area of the island used by Western Gulls as breeding territory. Although some tags were located in an area used by Brandt's Cormorant, this area also was used by Western Gulls and California sea lions (P. Morris, pers comm). As discussed previously, data from 2009 indicated that the majority of tag deposition probably was occurring during smolt outmigration (Feb-April). During 2009, Brandt's Cormorants bred later than usual (P. Morris, pers com.), and were absent from ANI during the period when the majority of the PIT tags arrived on the island. Meanwhile, the island was attended by adult Western Gulls setting up and defending breeding territories. Salmonids were not observed in diet samples collected from stomachs of Brandt's

Cormorants collected over offshore habitat in Monterey Bay between September 1974 and April 1975 (Baltz & Moorejohn 1975), a period that encompasses peak smolt outmigration (Shapavalov & Taft 1954, Hayes et al. 2004, in review). Salmonids also were absent from stomachs of 11 Brandt's Cormorants collected over inshore waters of Monterey Bay between December 1970 and March 1971 (Talent 1984). The specimens collected for these two studies were collected over waters in front of Moss Landing Harbor, so it is unknown whether diet of these birds reflects foraging habits of birds using ANI. A preliminary study of Brandt's Cormorant diet in Monterey Bay during the non-breeding season conducted during 3 years (2006-2008), however, indicated an absence of salmonids in pellets regurgitated by birds using ANI as a roosting site during winter 2006, 2007 and 2008 , L. Webb, pers comm.).

The majority of PIT tags on Año Nuevo Island were from fish tagged in the three watersheds in closest proximity to the island (Waddell, Gazos, and Scott). Recoveries of PIT tags on ANI only are indicative of predation by the population of gulls using ANI as a roosting and breeding site. Western Gulls have been observed bathing, loafing, and drinking water at five watersheds in San Mateo and Santa Cruz County where juvenile salmonids have been PIT-tagged (Table 2). Gulls eating salmonids at watersheds at greater distances from ANI (e.g. San Lorenzo and Soquel) may not be returning to ANI, therefore, could be depositing tags elsewhere, resulting in an underestimation of total predation on central California salmonids. Additionally, only adult Western Gulls return to ANI; juveniles roost elsewhere. Adult and juvenile Western Gulls have been observed eating juvenile salmonids with equal efficiency at Scott Creek, so tag recoveries on ANI

do not include predation by juvenile gulls, or by other species. Three other species of gulls occcur at these five watersheds, including California Gulls (*L. californicus*), Heermann's Gulls (*L. heermanni),* and Glaucous-winged Gulls (*L. glaucescens*). Additionally, only a fraction of juvenile salmonids are tagged with PIT tags on an annual basis. Because these estimates of predation do not include untagged fish, it is likely that considerable source of mortality for central California coho and steelhead is still being missed. If tagged and untagged juvenile salmonids are equally susceptible to predation by Western Gulls, estimates generated in this study can be applied to the untagged fish population.

Among watersheds in central California, the best estimates of annual smolt production exist for Scott Creek due to the location of a life-cycle monitoring station operated by the NOAA-SWFSC within this watershed (Table 8). Although annual estimates are not directly comparable among years due to slightly different sampling methods, estimates of wild coho smolt production varied from 240-790 (in 2004) to 3,005 ± 1,776 (in 2006). Estimates of annual wild steelhead smolt production range from 1,370 in 2003 to 16,563 ± 3,416 in 2007. Between 2003 and 2008, releases of fish from a hatchery located in the Scott Creek watershed averaged 2,088 coho and 6,302 steelhead. Between 2003 and 2008, 8 to 30% of wild coho smolts and 8 to 100% of hatchery coho were tagged with PIT tags annually in Scott Creek (Table 8). During the same period, 8 to 40% of the estimated annual wild steelhead population and 8 to 20% of hatchery fish were tagged (Table 8). The corrected predation rate for PIT-tagged salmonids in Scott Creek was 0.78%. Application of this correction factor to hatchery production and

population estimates of wild salmonids results in rough, minimum estimates of annual consumption of 15 hatchery coho, 72 hatchery steelhead, 53 wild coho and 147 wild steelhead by Western Gulls breeding on ANI. Populations of coho and steelhead in Scott Creek continue to decrease, however, and predation of the magnitude presented here is likely to influence population dynamics of these federally listed species. Additionally, wild smolt production estimates for steelhead in Scott Creek probably are overestimates. These estimates are based on smolt trapping during winter and spring, and include steelhead migrating to sea and steelhead making a first migration downstream to lagoon rearing habitat, therefore, annual estimates are essentially double-counting fish on their second downstream migration (Hayes et al. in press). If we assume that only steelhead >150 mm went to sea in 2009, and all fish <150 mm recruited to the lagoon, then true smolt production was ~3,000 steelhead (Hayes and Frechette, unpublished data). Mortality of juvenile salmonids during the freshwater rearing period has a disproportionate effect on the numbers of returning adult fish compared with mortality during other life stages (Good et al. 2007). Because the number of steelhead recruiting to ocean habitat on an annual basis, therefore, is less than previous estimates (Hayes et al. in press, Hayes and Frechette unpublished data), the level of estimated predation by Western Gulls at the creek mouth may be having a greater effect on returning adult populations than originally expected.

Although populations of salmonids in central California have decreased in recent years, federal protection, bans on organochlorine pollutants, and lack of predators have allowed many seabird populations to increase (Rudstam et al. 2004). The ability of many

seabirds to adapt to new food sources (e.g. human waste, fishing offal) and the creation of artificial nesting and roosting habitat also have enabled population increases for certain bird species (Collis et a. 2001, Oro et al. 2005). For instance, the population of Western Gulls at ANI has increased during recent years. Nearly 2,500 pairs were recorded nesting on ANI during 2003, compared with less than 1,000 pairs during 1987 (Thayer and Sydeman 2004). Increases in the ANI populations of Western Gulls populations likely are the result of increased food supply in the form of subsidies from local landfills and other sources of human waste (Chapter 2).

Predation of salmonids previously was not considered a significant source of mortality in central California watersheds (Bond 2006). Novel use of a mark-recapture model allowed me to create a corrected minimum estimate of predation for juvenile salmonids, and a correction factor that may be applied to future surveys of ANI to adjust the number of tags on the island to include the number that were on the island but not detected. This correction factor will improve future estimates of the extent of predation of juvenile salmonids by Western Gulls breeding on ANI. Based on application of this correction factor, predation of juvenile salmonids in central California was greater than expected, especially considering that recoveries of PIT tags from ANI only are indicative of predation by one age class (adults) of one species (Western Gulls) at one breeding site (ANI). This estimate does not take into account tags that are lost from the island before detection, tags that are not detected, and tags that are deposited by adult Western Gulls at other sites. The results of this study indicate that predation of salmonids by Western Gulls breeding on ANI may exceed 4% of juveniles in some watersheds. The majority of

predation by Western Gulls occurred in the last few meters of these watersheds, or immediately following ocean entry. The levels of predation presented in this paper indicate that avian predation may be one factor limiting recovery of these species in central California.

LITERATURE CITED

Anderson SK, Roby DD, Lyons DE, Collis K (2007). Relationship of Caspian tern foraging ecology to nesting success in the Columbia River estuary, Oregon, USA. Est Coast Shelf Sci 73:447-456

Arnason AN, Schwarz CJ (1999) Using POPAN-5 to analyse banding data. Bird Study 46(Suppl):127–S168

Balz DM, Morejohn GV (1977) Food habits and niche overlap of seabirds wintering on Monterey Bay, California. The Auk 94: 526-543

Bond MH (2006) Importance of estuarine rearing to central California steelhead (*Oncorhynchus mykiss*) growth and marine survival. Master of Arts Thesis, University of California Santa Cruz, 57p.

Bond MH, Hansen CV, Baertsch A, Hayes SA, MacFarlane RB (2007) A New Low-Cost Instream Antenna System for Tracking Passive Integrated Transponder (PIT)–Tagged Fish in Small Streams. Trans Am Fish Soc 136:562-566

Bond MH, Hayes SA, Hanson CV, MacFarlane RB (2008) Marine survival of steelhead (Oncorhynchus mykiss) enhanced by a seasonally closed estuary. Can J Fish Aquat Sci 65:2242–2252

Castro-Santos T, Haro A, Walk S (1996) A passive integrated transponder (PIT) tag system for monitoring fishways. Fisheries Research: 253-261

Collis K, Roby DD, Craig DP, Ryan BR, Ledgerwood RD (2001) Colonial waterbird predation on juvenile salmonids tagged with passive integrated transponders in the Columbia River estuary: vulnerability of different salmonid species, stocks, and rearing types. Trans Am Fish Soc 130: 385-396

Collis K, Roby DD, Craig DP, Adamany S, Adkins J, Lyons DE (2002) Colony size and diet composition of piscivorous waterbirds on the lower Columbia River: Implications for losses of juvenile salmonids to avian predation. Trans Am Fish Soc 131:537-550

Good TP, RS Waples, Adams P. (Editors). 2005. Updated status of federally listed ESUs of West Coast salmon and steelhead. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-66, 598 p.

Good TP, McClure MM, Sandford BP, Barnas KA, Marsh DM, Ryan BA, Casillas E (2007) Quantifying the effect of Caspian tern predation on threatened and endangered salmon in the Columbia River estuary. Endang Species Res 3:11-21

Hayes SA, Bond HM, Hanson CV, MacFarlane RB (2004) Interactions between endangered wild and hatchery salmonids: can the pitautumns of artificial propagation be avoided in small coastal streams? J Fish boil 65 (Supplement A) 101-121

Jolly GM (1965) Explicit estimates from capture-recapture data with both death and immigration—stochastic model. Biometrika 52:225–247

Lebreton J-D, Burnham KP, Clobert J, Anderson DR (1992) Modeling survival and testing biological hypotheses using marked animals: a unified approach with case studies. Ecol Monogr 62(1):67-118

Lindley, S. T., and coauthors. 2009. What caused the Sacramento River fall Chinook stock collapse? NOAA SWFSC FED Pre-publication report to the Pacific Fishery Management Council ftp://library.swfsc.noaa/lab_pubs/00920.pdf.
Lindley ST, Grimes CB, Mohr MS, Peterson W, Stein J, Anderson JT, Botsford LW, Bottom DL, Busack CA, Collier TK, Ferguson J, Garza C, Grover AM, Hankin DG, Kope RG, Lawson PW, Low A, MacFarlane RB, Moore K, Palmer-Zwahlen M, Schwing FB, Smith J, Tracy C, Webb R, Wells BK, Williams TH What caused the Sacramento River fall Chinook stock collapse? Pre-publication report to the Pacific Fishery Management Council, March 18, 2009.

MacFarlane RB, Wells B, Hayes SA (2008) Coho and Chinook Salmon Decline in California during the Spawning Seasons of 2007/08. NOAA SWFSC FED

Major III, WW. Grassley JM, Ryding KE, Grue CE, Pearsons TN, Tipton DA, Stephenson AE (2005) Abundance and consumption of fish by California gulls and Ring-billed gulls at water and fish management structures within the Yakima river, Washington. Waterbirds 28(3):366-377

Oro D, de Leon A, Minguez E, Furness RW (2005) Estimating predation on breeding European storm-petrals (Hydrobates pelagicus) by yellow-legged gulls (Larus michahellis). J Zool Lond 265:421-429

Parsons KM, Piertney SB, Middlemas SJ, Hammond PS, Armstrong JD (2005) DNA-based identification of salmonid prey species in seal faeces. J Zool Lond 266:275-281

Pradel R (1996) Utilization of capture-mark-recapture for the study of recruitment and population growth rate. Biometrics. 52(2):703-709

Roby DD, Lyons DE, Craig DP, Collis K, Visser GH (2003) Quantifying the effect of predators on endangered species using a bioenergetics approach: Caspian terns and juvenile salmonids in the Columbia River estuary. Can J Zool 81: 250-265

Roussel JM, Cunjak RA, Newbury R, Caissie D, Haro A (2004) Movements and habitat use by PIT-tagged Atlantic salmon parr in early winter: the influence of anchor ice. Freshw Biol 49:1026–1035

Ruggerone GT (1986) Consumption of migrating juvenile salmonids by gulls foraging below a Columbia River dam. Trans Am Fish Soc 115:736-742

Ryan BA, Ferguson JW, Ledgerwood RD, Nunnallee EP (2001) Detection of passive integrated transponder tags from juvenile salmonids on piscivorous bird colonies in the Columbia River basin. North Am J Fish Manage 21:417-421

Ryan BA, Smith SG, Butzerin JAM, Ferguson JW (2003) Relative Vulnerability to Avian Predation of Juvenile Salmonids Tagged with Passive Integrated Transponders in the Columbia River Estuary Trans Am Fish Soc 132:275-288

Seber GAF (1965) A note on the multiple-recapture census. Biometrika 52:249–259

Shapovalov L, Taft AC (1954) The life histories of the steelhead rainbow trout (*Salmo gairdneri gairdnrei*) and silver salmon (*Oncorhynchus kisutch*). California Department of Fish and Game, Fish Bull 98:375p.

Schwarz CJ, Arnason AN (1996) A General Methodology for the Analysis of Capture-Recapture Experiments in Open Populations. Biometrics 52:860-873

Spence BC, Harris SL, Jones WE, Goslin M, Agrawal A, Mora E (2005) Historical occurance of coho salmon in streams of the central California coast coho salmon evolutionarily significant unit. NOAA-TM-NMFS-SWFSC-383, 89p.

Thayer JA, Sydeman WJ (2004) Long-term studies of seabirds on Año Nuevo Island and mainland, 2003. In: Final Report to the Monterey Bay National Marine Sanctuary – Sanctuary Integrated Monitoring Network. Stinson Beach: Point Reyes Bird Observatory; 10, http://www.mbnms-simon.org/docs/project/100251_report.pdf

Weise MJ, Harvey JT (2005) Impact of the California sea lion *(Zalophus californianus)* on salmon fisheries in Monterey Bay, California. Fish Bull 103:685–696

White GC, Burnham KP (1999) Program MARK: survival estimation from populations of marked animals. Bird Study 46:120–138

Wright BE, Riemer SD, Brown RF, Ougzin AM, Bucklin KA (2007) Assessment of harbor seal predation on adult salmonids in a Pacific Northwest estuary. Ecological Applications 17(2):338-351

Chapter II

Birds eat fish: Tracking avian predation of juvenile salmonids in central California

ABSTRACT

Recovery of Passive Integrated Transponders (PIT Tags) on Año Nuevo Island (ANI) indicated that Western Gulls (*Larus occidentalis*) were preying upon coho (*Oncorhynchus kisutch*) and steelhead (*O. mykiss*) in central California watersheds. This study was conducted to (1) improve estimates of predation of central California salmonids by locating and scanning additional roost sites for PIT tags; and 2) examine movements and foraging habits of Western Gulls using ANI in relation to availability of juvenile salmonids. No additional roost sites were located during this study. Observation of predation of juvenile salmonids by Western gulls was rare; 20 predation events were observed during 198 hours of observations at Scott and Waddell Creeks during 2008 and 2009. Western Gulls exhibited individual variation in movements and foraging location, however, most detections of radio-tagged gulls occurred within 25 km of ANI during prospecting, incubation, and chick-rearing phases of the breeding cycle, which coincided with migration of juvenile salmonids from fresh to salt water. Relative susceptibility to predation decreased with increasing distance from ANI when juvenile salmonids were most vulnerable to predation. Western Gulls were present at Scott and Waddell Creeks during daylight hours (90% of detections), whereas juvenile salmonids were present at night (90% of detections). Seventy-one percent of radio-tagged Western Gulls that used ANI were detected at a landfill 25 km south of ANI. Subsidy of anthropogenic food likely explains recent increases in numbers of Western Gulls breeding on ANI. Although predation was rare, and little temporal overlap occurred between gulls and salmonids at Scott and Waddell Creeks, predation was 100% when overlap did occur. Increases in the

ANI breeding population combined with concurrent decreases in salmonid populations has resulted in levels of predation that may be unsustainable when combined with other pressures faced by these imperiled salmonid populations.

INTRODUCTION

Predation by birds and mammals is a significant source of mortality for Eastern Pacific salmon of the genus *Oncorhynchus* (Collis et al. 2001, Collis et al. 2002, Major et al. 2005, Parsons et al. 2005, Weise & Harvey 2005, Anderson et al. 2007, Good et al. 2007). Whereas many runs of *Oncorhynchus* salmonids are listed as threatened or endangered under the U.S. Endangered Species Act (Spence et al. 2005), many species of piscivorous birds and mammals have experienced population increases during recent decades because of protection afforded by the Migratory Bird Treaty Act of 1918 (MBTA; 16 U.S.C.703-712) and the Marine Mammal Protection Act of 1972. Mortality of juvenile salmonids during the freshwater and estuarine life history stages has a disproportionate effect on the numbers of returning adult fish, compared with mortality during other life stages (Kareiva et al. 2000, Good et al. 2007). Understanding the role of predation on survival of juvenile salmonids during freshwater and estuarine rearing periods, therefore, is necessary for predicting population dynamics and for targeting recovery strategies for federally listed *Oncorhynchus* salmonids.

The central California coastal coho salmon Evolutionary Significant Unit (CCC-coho ESU) is listed as endangered and the central California coastal steelhead Distinct Population Segment (CCC-steelhead DPS) is listed as threatened by the Endangered

Species Act. To enhance understanding of the population biology and marine survival for CCC-coho and CCC-steelhead, NOAA's Southwest Fisheries Science Center (SWFSC) began a program to tag juvenile salmonids with Passive Integrate Transponders (PIT tags). As of May, 2010, greater than 33,000 PIT tags have been deployed in juvenile salmonids in six watersheds in San Mateo and Santa Cruz Counties (Table 1, Chapter 1).

Recoveries of 252 PIT tags on Año Nuevo Island (ANI), an important breeding and roosting site for several species of piscivorous seabirds and marine mammals, indicated that predation may be an important source of mortality limiting recovery for coho and steelhead in San Mateo and Santa Cruz counties (Chapter 1). Timing of tag deposition on ANI indicates that predation occurs predominantly during spring, when juvenile steelhead and coho (termed smolts) are migrating from stream to ocean habitat. The majority of tags recovered on ANI were recovered in areas of the island used by Western Gulls for breeding and roosting. Additionally, because ANI serves as breeding territory, juvenile gulls generally are restricted from the island by adults, so tags deposited on ANI only represent predation of juvenile salmonids by adult Western Gulls. Recoveries of PIT Tags from ANI indicate predation of juvenile salmonids by adult Western Gulls breeding on ANI exceeds 4% of all tagged fish in some central California watersheds, an appreciable source of mortality for these depleted populations (Chapter 1).

The ecology and behavior of predator and prey will affect susceptibility of a species to predation. Timing of breeding, body size, energetic requirements, foraging strategy (surface feeding, diving, or wading), foraging location within a watershed, and

age of the predator all affect predation rates on juvenile salmonids (Wood 1987a,b, Collis et al. 2001, 2002, Major et al 2005, Anderson et al. 2007). Timing of smolt outmigration, numbers and sizes of fish, smolt behavior, and availability of alternative prey sources also may cause juvenile salmonids to be more or less susceptible to predation (Wood 1987 a,b; Scheel & Hough 1997; Collis et al. 2001, 2002; Roby et al. 2003; Anderson et al. 2007). Because the Western Gull is the primary predator depositing PIT tags on ANI, understanding foraging ecology and behavior of Western Gulls, especially in relation to availability of juvenile salmonids as prey, is essential to assessing the effects of this predator on recovery of ESA listed populations of salmonids in central California.

Western Gulls are large larids, which range from Baja California to northern Washington (Spear et al. 1986). Like many species of seabirds, Western Gulls are considered central place foragers during the breeding season, thus are limited in distance travelled and duration of foraging trips by the need to return to their nests (Sirdevan and Quinn 1997). If a bird is foraging optimally, it should maximize energetic efficiency of foraging by taking larger or more energetically-rich prey or remaining in prey patches for a greater period of time when foraging at greater distances from the central place, if the cost of pursuing and transporting the prey is unrelated to size of prey (Schoener 1979, Orians and Pearson 1979, Martindale 1982). Energetic efficiency, however, may not solely govern foraging theory (Charnov 1976).

Risk provides one set of alternative hypotheses to optimal foraging theory (Charnov 1976). While parents are foraging, nests are vulnerable to attacks from predators and conspecifics, which may cause injury or loss of young (Martindale 1982,

Pierotti & Annett 1990, 1991). At greater densities, competition for breeding space and frequency of aggressive interactions among conspecifics increased within colonies of nesting gulls (Pierotti 1981). When competition for nesting space is great, therefore, costs of leaving nests unattended may be greater than benefits of maximizing food delivery to young (Martindale 1982, Pierotti and Annett 1991).

The breeding colony of Western Gulls at ANI has increased during recent years, from 1,000 pairs in 1987 to nearly 2,500 pairs in 2003 (Thayer and Sydeman 2004). This increase in population size seems to have resulted in increased competition for nesting space, thus adults are returning to ANI to prospect territories earlier than previous years (P. Morris, pers comm.). Western Gulls, therefore, should be acting as central place foragers and remaining closer to ANI while prospecting territories, incubating eggs, and during early chick-rearing than either late chick-rearing or after chicks fledge.

Increases in gull populations worldwide have been attributed to the ability of these generalist species to forage on anthropogenic sources of food, including discards from fisheries (Furness et al. 1992) and human refuse from landfills (Hunt 1972, Belant 1993, Duhem 2003, Ramos 2009). Western Gulls breeding on ANI have access to several sources of anthropogenic food. Landfills are located 24.5 km (Santa Cruz) and 51.2 km (Watsonville) from ANI, and the Santa Cruz Harbor, which supports a moderate fishing fleet, is located 35 km from ANI. These three locations are within the foraging range of Western Gulls (80 km, Spear 1988). Western Gulls foraging in Monterey Bay also forage on fishery discards (Balz and Morejohn 1972) and in agricultural fields (pers.

obs). These food subsidies likely are responsible for the increase in the breeding population at ANI.

Like many bird species, larids forage opportunistically, and are capable of exploiting prey when it is available (Major et al. 2005). Outmigration of juvenile salmonids from central California streams occurs from January to June (Shapavalov and Taft 1954), when Western Gulls are most tied to their breeding site. Western Gulls breeding on ANI, therefore, may alter foraging patterns during smolt outmigration to exploit this ephemeral prey source.

The objective of this study was to examine movements and foraging habits of Western Gulls to assess susceptibility of juvenile salmonids to predation by Western Gulls. Specific objectives were to (1) improve estimates of predation of juvenile salmonids from central California watersheds by using radio-telemetry to locate roosting sites used by Western Gulls (in addition to Año Nuevo Island), then to scan for PIT tags in areas used by Western Gulls, including Southeast Farallon Island; (2) conduct visual scans of local watersheds during daylight hours to note gull presence and abundance on a weekly basis, and to document predation attempts by gulls in the lower estuary and creek mouth; and (3) examine movements of radio-tagged adult Western Gulls in relation to stage in the breeding cycle, availability of juvenile salmonids as a source of prey, and alternative foraging sites.

If Western Gulls were acting as central place foragers, detections of radio-tagged Western Gulls would decrease with distance from ANI during the breeding season, whereas after chicks fledged, radio-tagged gulls would be detected at greater distances

from ANI. If Western Gulls breeding at ANI were acting as subsidized predators, I would expect to see a large proportion of them foraging in the Santa Cruz landfill, the closest and largest anthropogenic food source to the island. Additionally, if Western Gulls were targeting juvenile salmonids as a source of prey when available, it was expected that presence of Western Gulls at creek mouths would be greatest during the time period when the greatest smolt outmigration was occurring, on daily and weekly time scales.

STUDY AREA

Although PIT tags from five watersheds located in San Mateo and Santa Cruz counties have been detected on ANI, two watersheds, Scott Creek (37° 2' N, 122° 13' W) and Waddell Creek (37 ° 5' N, 122° 16' W) were chosen as the focus of this study (Fig. 1). Scott and Waddell Creeks are representative of coastal watersheds in central California, access is logistically feasible, and because of on-going monitoring of salmonids by SWFSC, run time and life history for coho and steelhead spawning in these watersheds are well understood.

Scott and Waddell Creeks are small, coastal watersheds, each terminating in a small estuary that becomes a freshwater lagoon during summer months, a feature typical of watersheds in central California (Shapovalov and Taft 1954, Hayes et al. 2004). During summer, deposition of beach sand creates a sandbar across the river mouth, blocking the estuary from the ocean. Generally between November and January, high flows associated with winter rains break open the sandbars and open the estuary to the sea, allowing adult salmon access to spawning territory and smolts access to the ocean

(Shapovalov and Taft 1954). Outmigration of coho smolt occurs primarily in April and May, whereas outmigration of steelhead occurs from January through June, with the largest smolts passing through instream smolt traps in February and March (Shapavalov and Taft 1954, Hayes et al. in review).

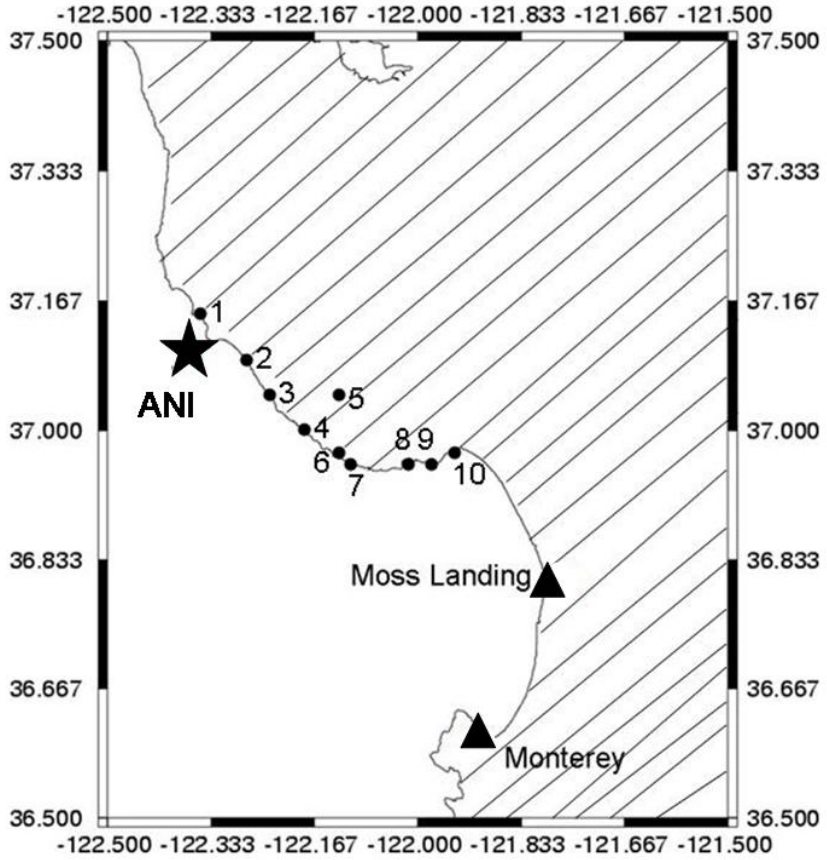

Figure 1: Study area depicting ANI (star) and locations where radio-tagged gulls were tracked by car. Land is denoted by lines. Sites are numbered numerically and distance from ANI (km) follows site names. 1) Gazos Creek (6.6 km); 2) Waddell Creek (5.5 km); 3) Middle (10.5 km); 4) Scott Creek (12.0 km); 5) Davenport (16.0 km); 6) Santa Cruz Landfill (25.4 km); 7) Long Marine Lab (25.0 km); 8) Natural Bridges (30.4 km); 8) San Lorenzo River (33 km); 9) Twin Lakes (34.3 km); Soquel Creek (38 km), and 10) Aptos Creek. Moss Landing and Monterey (triangles) are shown for reference.

Año Nuevo Island (ANI) is a 10 hectare island located 1.6 km off Point Año Nuevo, San Mateo County, California (37 ° 48' N 122° 20' W), which provides breeding and resting habitat for several species of marine birds and mammals. The island is owned and operated by California State Parks as part of the ~1617 hectare Año Nuevo State Reserve, and is accessible only to permitted researchers. Birds using ANI include Western and Heerman's Gulls (*Larus occidentalis* and *L. heermani*), two species of cormorants (*Phalacrocorax penicillatus* and *P. pelagicus*), Pigeon Guillemots (*Cepphus columba*), Rhinocerous Auklets (*Cerorhinca monocerata),* and Brown Pelicans (*Pelicanus occidentalis*; Thayer & Sydeman 2004). The island also provides breeding and resting habitat for California sea lions (*Zalophus californianus*), Steller sea lions (*Eumetopias jubatus*), and northern elephant seals (*Mirounga angustirostris*).

Southeast Farallon Island (SEFI, 37 ° 43' N 123° 2' W) is a 419 hectare island, located 43 km west of the Golden Gate (37° 02' N and 122° 13' W) and is part of the Farallon Islands National Wildlife Refuge. Southeast Farallon Island supports the largest breeding colony of Western Gulls in California (15,095 breeding birds, NOAA 2007). In addition to Western Gulls, SEFI provides breeding and resting habitat for Brandt's, Pelagic, and Double-crested Cormorants (*Phalacrocorax auritas*), Pigeon Guillemots, Common Murres (*Uria aalge*), Cassin's Auklet (*Ptychoramphus aleuticus)*, Tufted Puffin (*Fratercula cirrhata*), Black Oystercatchers (*Haematopus bachmani*), Rhinoceros Auklets, Ashy and Leach's Storm-petrels (*Oceanodroma homochroa* and *O. leucorhoa*), California sea lions, Steller sea lions, northern fur seals (*Callorhinus ursinus*), and

northern elephant seals. Whereas SEFI is located 100 km north of Scott Creek, ANI is located only 12 km north.

METHODS

Abundance Estimates and Predation Observations

Visual observations were conducted at Scott and Waddell Creek during daylight hours to count gulls present and to document predation attempts by gulls in the lower estuary and creek mouth. Observations were conducted on a weekly basis during winter and spring 2008 and 2009 to coincide with smolt outmigration. Observations of avian predators were conducted at both creeks during one day, unless poor weather, daylight, or number of observers prevented observations at both sites, in which case observations were conducted on subsequent days. Counts of gulls were made using 8x42 binoculars, and predation observations were conducted using the naked eye and aided with binoculars or a spotting scope if necessary.

Initially, observations were conducted once per week at either Scott or Waddell Creek for a period of one tidal cycle (alternating between starting at high or low tide) during daylight hours, beginning March 2008. At the start of the observation period all gulls were counted. Following the count, an individual gull was randomly selected and observed for a period of 5 minutes or until it exited the creek, at which point another gull was selected for observation. Any predation attempts during the 5 minute focal follow were recorded. After a period of 30 minutes, all gulls were counted. This cycle was repeated for the duration of the tidal cycle (generally 5 or 6 hours). During April 2008, a

new protocol was adopted, modified from Major et al. (2005). Observations were conducted in hour long cycles, which began at sunrise, and were conducted until no gulls were observed for a period of one hour. At the start of the hour, gulls were counted. When numbers of gulls present exceeded ~300, photos were taken, and counted by 2 independent observers using Adobe Photoshop software (Adobe Systems Incorporated, San Jose CA). Following the initial count, observers watched the creek mouth and lower estuary for a period of 20 minutes. All predation attempts within the 20 minute observation period were recorded. Following the 20 minute observation period, a second count was made, followed by a second 20 minute observation period. At the end of the second observation period, a third count was conducted. Observers then were given a break (generally 10 to 15 minutes) from the end of the final count to the start of the next hour.

During March 2009, observations were conducted from sunrise to sunset, to examine within day variability in gull use at Scott Creek during smolt outmigration. During visual observations at Scott Creek, gulls were counted in three locations: 1) in the creek or on the beach adjacent to the creek, 2) in the ocean in front of the creek mouth, and 3) on a rocky intertidal area located to the north of the creek mouth. For observations from sunrise to sunset, the same protocol consisting of 20 minute predation observations separated by counts was used. Visual observations were conducted at Scott and Waddell Creeks during March to August 2008, and January through March 2009. During the remainder of the year, one count per day was made at Scott Creek once every 7 to 14 days.

Gull Captures and Tagging Methods

Captures of Western Gulls were conducted during May 2008, and February and May 2009 on beaches at Scott and Waddell Creeks. Capture methodology was consistent across years. Gulls were captured using a cannon net which was either propelled using black powder, or an air canister under pressure. Nets were set on beaches at Scott and Waddell Creeks before sunrise (between 0400 and 0700 hours). Gulls were attracted to the net using a variety of bait, including bread, crackers, dead fish, and cookies. The net was fired once a sufficient number of gulls had gathered in front of the net.

Upon capture, birds were removed from the net, placed in cardboard pet carriers, and transported 26 km (from Scott Creek) or 29 km (from Waddell Creek) to the NOAA SWFSC Fisheries Ecology Division, in Santa Cruz, CA. All Western Gulls were marked with steel identification bands obtained from the Bird Banding Lab (Patuxent, MD), and with colored poultry bands with alpha-numeric combinations. A subset of Western Gulls were tagged with VHF radio transmitters. After processing, gulls were returned to the capture location and released. Gulls were observed until they flew away to ensure that no birds were injured during handling.

During 2008, 33 Western Gulls were tagged with tail-mounted VHF radio transmitters (34 mm long by 11 mm diameter and 9 g mass; ATS, Isanti, MN). Tags were attached to the center two rectrices (from which barbs had been removed) using cyanoacrylate glue and Tesa tape (Tesa Tape Inc., Charlotte, NC). During 2009, backpack mounted VHF radio transmitters (49 mm long by 16 mm diameter and 19 g mass; ATS, Isanti, NM) were attached using harnesses constructed either using neoprene

(D. Craig, pers comm.) or Teflon ribbon (Belant et al. 1998). Neoprene harnesses were constructed of 1 mm thick, single-backed neoprene. Tags were attached to the harness using Teflon ribbon, and surgical suture reinforced with cyanoacrylate glue was used to attach harnesses to gulls. Teflon wing harnesses were constructed using tubular Teflon ribbon and either metal J-clips (referred to as Teflon harnesses) or surgical suture reinforced with cyanoacrylate glue (referred to as Teflon-suture harnesses). Average mass of the tag and harness package (Neoprene and Teflon-types) was 25.56 g, or 2.57% of the average mass of gulls handled ($\bar{x} = 998.7g, SD = 12.4$).

Radio-tracking Methods

Radio-tagged Western Gulls were tracked by car along a section of coastline ranging from Pigeon Point during 2008 (37° 10' N, 122° 23' W) or Gazos Creek during 2009 (37° 9' N, 122° 21' W) in the north to Aptos Creek (36° 58' N, 121° 54' W) in the south (both years, Fig. 1). Monitoring locations were located approximately 4.8 km apart to ensure coverage of the coastline (tag detection range was 4.8 to 9.7 km). Sites also were chosen to include the five creeks from which PIT tags on ANI originated, and potential alternative foraging sites. Radio-tagged Western Gulls were tracked during both years using a portable radio receiver (R4000, ATS, Isanti, MN) and three element Yagi antenna. During 2008, radio-tracking was conducted approximately once per week between 20 May and 31 July. Surveys were conducted during nighttime to locate night roost sites and during daylight hours to verify whether locations where birds were detected during night time surveys were accessible to scan for PIT tags. During 2009,

radio-tracking was conducted every 7 to 14 days during daylight hours and at night; date, start time, and direction of travel (north to south or south to north) were randomized to account for daily variation in gull behavior. In addition, three aerial surveys were flown (2008: n=1, 2009: n=2), which encompassed an area from Point Sur in the south to San Francisco Bay in the north, and out to Farallon Islands (approximately 250 km). The aerial survey during September 2008 was an attempt to locate any functioning radio-tags that were outside of the study area. Aerial surveys were flown in June 2009 during chick rearing, and September 2009 after all chicks were expected to have fledged to examine distances travelled by birds that used ANI during the 2009 breeding season, and to locate birds or tags which had dispersed out of the primary study area.

During 2009, automatic data collection systems, consisting of a 4-element Yagi antenna, radio receiver (R4000, ATS, Isanti, MN), and datalogger (DCCII, ATS, Isanti, MN) were installed at Scott and Waddell Creeks, and Año Nuevo State Reserve to continually log presence or absence of radio-tagged gulls at each location. A test tag was placed at each site, to test the efficiency of each continuous data collecting system. These automatic data collection systems (hereafter referred to as DCCs) were operated from just before gulls were captured during late February 2009 until mid-October 2009. Detections of gulls on capture dates were excluded from analysis. Between 1 March and 27 July 2009, the DCCs were programmed to scan through 41 different radio-frequencies (the frequency of each radio-tag deployed plus the test tag) and listen for each frequency for a period of 10 sec, every 15 minutes. On July 28 2009, DCCs were reprogrammed, causing the receiver to listen for each frequency for a period of 10 seconds,

approximately every 7 minutes. Appropriate considerations were taken for the change in methodology (see Discussion), and data collected using 7 and 15 minute sampling intervals were analyzed together. A radio-tagged gull was considered present at a site if it was detected one or more times by the DCC.

Data collected by DCCs at each watershed were used to determine attendance of tagged Western Gulls to examine 1) individual variation in attendance patterns, 2) variation in attendance patterns in relation to stages of the Western Gull breeding cycle, and 3) variation in attendance patterns in relation to availability of juvenile salmonids during smolt outmigration. Stages of the breeding season were defined based on breeding phenology of Western Gulls using ANI during 2009. The prospecting phase of the breeding cycle was defined as the period from the start of the study (1 March) until the day before the first egg was found on ANI (30 April). The period from the date of the first egg found on ANI (1 May) until the day before the first chick was seen (3 June) was defined as the incubation stage of the breeding cycle. The chick-rearing stage was defined as the date the first chick was seen on ANI (4 June) until the date at which approximately half of the chicks were no longer being fed by parents (15 August, P. Morris, pers. comm). The post-fledging period was defined as a two-month period following the date at which approximately half of the chicks were no longer being fed by parents (16 August – 16 October).

Availability of juvenile salmonids and the period of smolt outmigration was determined using detections of PIT-tagged juvenile salmonids by an instream PIT tag antenna (Bond et al. 2007) installed upstream of the mouth of Scott Creek. The PIT tag

antenna was installed on 26 March 2009, approximately 100 m upstream from where Scott Creek enters the ocean. The antenna operated until lagoon closure, on 21 July 2009. The number of fish detected passing through the antenna on a daily basis was used to determine the period of peak smolt outmigration. Only minimum numbers of tagged fish detected are presented in this manuscript, as efficiency of the PIT tag antenna was variable, and there were periods of time when the antenna was inoperable. Detections of tagged Western Gulls by the DCC at Scott Creek were compared with detections of PIT-tagged juvenile salmonids by the PIT tag antenna to examine the extent of overlap between presence of gulls at the creek mouth and movement of salmonids out of the creek. Detections of fish during the peak smolt outmigration period were pooled to examine the time of day (by hour) during which fish passage out of the freshwater system occurred, and were compared with detections of radio-tagged Western Gulls at Scott Creek across the same range of dates. It was assumed that behavior of tagged birds and fish did not differ from behavior of untagged individuals, therefore, untagged birds were expected to be present at Scott Creek during the same hours that tagged birds were detected by the DCC, and untagged salmonid smolt were expected to migrate to sea during the same period of time as tagged smolts.

PIT Tag Scanning: Southeast Farallon Island

Between 6 and 11 September 2009, I scanned for PIT tags in areas of SEFI used by Western Gulls, Brandt's Cormorants (*Phalacrocorax penicillatus*) and Common Murres (*Uria aalge*) for breeding and roosting (for methods, see Chapter 1). Access to

scan SEFI for PIT tags was granted by the U.S. Fish and Wildlife Service. The main objective of this trip was to compare predation of juvenile salmonids originating in watersheds in Santa Cruz and San Mateo counties by Western Gulls using ANI with predation by Western Gulls using SEFI.

Statistical Analysis

All statistical tests were performed using SYSTAT version 10 (SPSS Inc, 2000) for Windows XP or SPSS Version 16 (SPSS Inc, 2007) for Mac OS 10. Means are presented with standard deviation or standard error, as appropriate.

RESULTS

Observation of Predation

Predation observations were conducted from March to August (Scott Creek) and March to July (Waddell Creek) during 2008. Using the original protocol (5 minute focal follows conducted during 30 minute observation periods), no predation events were recorded during 28 hours of observations at Scott Creek (8 March to 8 April; n = 5) and 20.25 hours at Waddell Creek (13 and 31 March). Although focal gulls were followed during these observations, the size of the area observed was small and two observers were present. I believe, therefore, that predation events would have been observed, had they occurred.

During visual observations conducted using the protocol adopted during April 2008 (two observation periods of 20 min per hour, with all predation events recorded), no

predation events occurred during 31.82 hours of observations at Waddell Creek (17 April to 10 July; n = 9 occasions). Between 11 April and 14 August, 41.07 hours of observations were conducted at Scott Creek (n = 14 occasions). During a three-hour period on 11 April 2008, twenty juvenile salmonids swam down the last 20 m of Scott Creek, just before it entered the ocean. All fish observed were captured and eaten by Western Gulls. Gulls fought over captured fish, with some gulls successfully pirating a fish from the gull that originally caught the fish. Of the 20 fish eaten, 50% were eaten by juvenile Western Gulls and 50% were eaten by adults, indicating that juveniles and adults prey upon free-swimming juvenile salmonids.

No predation events were observed during summer after sandbar formation. Numbers of gulls observed bathing in the lagoon often were great (as many as 260 gulls, $\bar{x}$ = 116), therefore, predation events could have been missed. Because predation events were rare even when observation conditions were ideal, and observations were time- and personnel-intensive, observations only were conducted during the smolt outmigration period in 2009. No predation events were observed during 2009, despite 21.4 hours of observations at Waddell Creek (n = 8 occasions between January and March) and 55.15 hours of observations at Scott Creek (n = 12 occasions between January and March).

Abundance Estimates and Flock Composition

Between 16 and 19 March 2009, 28 hours of observations were conducted at Scott Creek, beginning at sunrise and ending at sunset. Mean number of birds per count (all locations combined: creek, beach adjacent to the creek, ocean, and rocky intertidal) was

209.65 (SD = 168.75). A mean 103.92 (SD = 97.94) were in the creek, on the beach, and in the ocean directly in front of the creek mouth and a mean 105.73 (SD = 115.92) were in the rocky intertidal area. The number of gulls present increased beginning approximately two hours after sunrise, and numbers were greatest around 1200 hours. After noon, numbers decreased steadily until about 1700 hours (Fig. 2, Total count). When gull presence was examined by location, the number of gulls on the beach, in the creek mouth, or in the ocean increased from sunrise until 0900 hours, and then decreased, followed by a second peak in numbers present at approximately 1200 hours. Numbers then decreased until 1700 hours, when few or no gulls were present during all counts (Fig 2, Beach/Stream/Ocean Count). Conversely, between sunrise and 1000 hours, the number of gulls in the rocky intertidal area was less than the number of gulls in the other three locations combined. At approximately 1000 hours, however, the number of gulls in the intertidal area increased, and remained greater than the number of gulls at the other three locations. A peak in gull numbers in the intertidal area was observed at 1200 hours (Fig. 2). After 1500 hours, numbers began to decrease, but remained greater than the number of birds present at the other three locations, until 1700 hours, when numbers were minimal at all four locations (Fig. 2). During the four days in March when this study was conducted, low tide occurred in the morning, ranging from 0901 hours on 16 March (0.09 m) to 1231 hours on 19 March (0.15 m). High tide ranged from 1613 hours on 16 March (0.96 m) to 2003 hours on 19 March (1.1 m).

To examine annual variation in gull attendance at Scott Creek, randomly generated times were selected for all dates when predation observations were conducted

(n = 23) and combined with data from daily counts conducted at Scott Creek between September 2009 and July 2010. Daily counts (n = 56) occurred every 7-14 days, with the exception of August 2009, when 49 days elapsed between the survey conducted 8 August 2009 and 22 September 2009 because a forest fire prevented access to the watershed. Counts were conducted between 0659 and 1400 hours, with a mean time of 0944 hours. When randomly selected counts from the high resolution data collected during predation observation were combined with data from point counts, the mean number of birds per count was 90.11 (SD = 115.05), with a range of 0 to 699 birds (n = 87). The greatest number of birds was observed during surveys conducted between July and September (Fig. 3). The greatest variation (SD) in number of birds per count was observed during July. Greater variation in number of gulls occurred during the late winter and spring (January to May) than during autumn and winter (October to December). Because of observer experience, these counts include all gulls present, and not just Western Gulls.

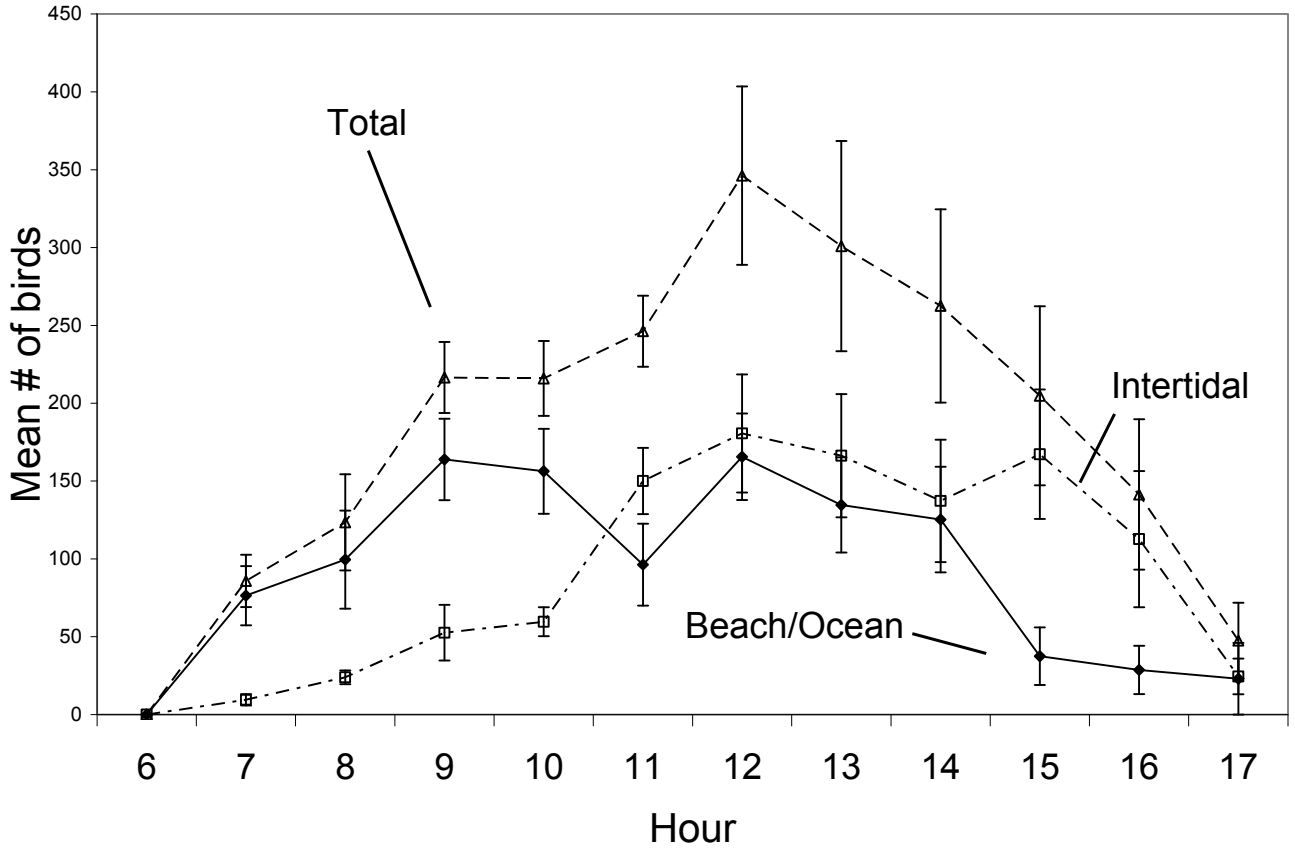

Figure 2: Gulls present at Scott Creek 16-19 March 2009 from sunrise to sunset. Mean number (± SE) of gulls counted per hour for: 1) gulls on the beach, in the stream or ocean (solid line, solid diamond) and gulls in the rocky intertidal (dashed line, open square) separately, and 2) all locations combined (dashed line, open triangle).

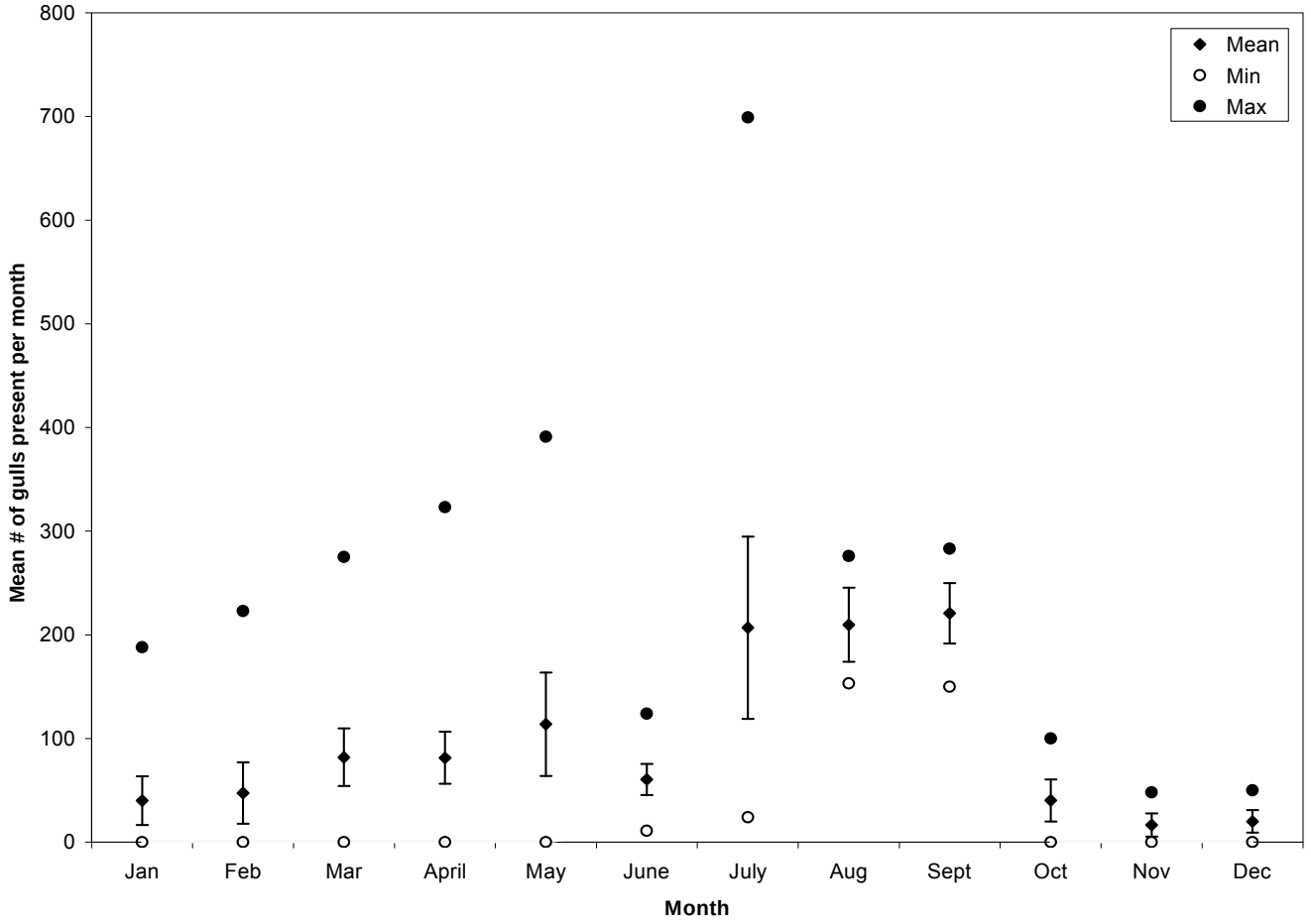

Figure 3. Mean number (± SE) of gulls (closed diamond) counted at Scott Creek per month, March 2008 to July 2010. The minimum (open circle) count and maximum (closed circle) count also are presented.

Daily counts were not conducted at Waddell Creek, therefore, to examine variability in gull presence at Waddell Creek, one count was randomly selected from each day when predation observations were conducted, and those counts were averaged. Counts were conducted between March and July 2008, and January to March 2009. Number of gulls present ranged from 0 to 204 gulls, and average flock size was 75.5 gulls, however, flock size varied greatly (SD = 78.8). The greatest counts occurred during February (n = 5) and April (n = 3), and the least amount of variability was observed during March (n = 3) and June (n = 3)

Observers were not always capable of identifying species of gulls at Scott and Waddell Creeks. To examine flock composition by species, therefore, all counts when species ID was recorded were used (Scott Creek: n = 57 counts conducted on 14 dates, Waddell Creek: n = 32 counts conducted on 11 dates) from predation observations conducted during 2008 and 2009 (non-zero counts only). Mean flock composition at Scott Creek was comprised of Western Gulls ($\bar{x} = 56\%, SD = 33\%$), California Gulls ($\bar{x} = 14\%, SD = 23\%$), other species ($\bar{x} = 3\%, SD = 14\%$), and unidentified gulls ($\bar{x} = 27\%, SD = 30\%$). Other species present were primarily Glaucous-winged Gulls (*Larus glaucescens*) during winter and Heermann's Gulls during summer. The same method was used to examine flock composition by age class (adult or juvenile). At Scott Creek, there were 117 occasions when gulls were present and age class was recorded, that occurred on 19 dates during 2008 and 2009. Mean flock composition was 61% adults (SD = 25%), and 34% juveniles (SD = 23%). The remaining 5% of gulls (SD = 19%)

were not assigned an age class. At Waddell Creek, flock composition was similar, with mean flock composition of 69% adults (SD = 30) and 31% juveniles (SD = 70%).

Location of Alternative Roost Sites

During May of 2008, 32 tail-mounted radio-transmitters were deployed on juvenile and adult Western Gulls captured on beaches at Scott (n=12) and Waddell (n=20) Creeks (Table 1), 22 of which were detected after release. During processing, handlers failed to record age class for many birds (Table 1). All known adults (n=9) that were radio-tagged were detected after release. Additionally 11 birds of unknown age class were detected after release. The radio-tagged gulls which were not detected after release were of unknown age class (n=10) or sub-adults (n=2).

Table 1. Number of Western Gulls handled by age class (2008). Birds listed as radio-tagged received tail-mounted radio transmitters and identifying leg bands; gulls listed as banded received identifying leg bands only.

Age class	Radio-Tagged	Banded
Juvenile	0	24
Subadult	2	1
Adult	9	2
Not Recorded	21	9
Total	32	35

Five night-time and seven daytime radio-tracking surveys were conducted between 11 June and 31 July 2008. An additional daytime survey was conducted after the aerial survey, on 23 September, during which no radio-tagged gulls were detected. During nighttime surveys, at least one radio-tagged gull was detected at ANI on all

surveys except 31 July, when only one bird was detected within the entire survey area. At least one gull was detected at ANI during all daytime surveys. In total, 13 individual radio-tagged gulls were detected at ANI. Six gulls were detected during daytime and nighttime surveys (5 adults, 1 sub-adult), 5 gulls only were detected at ANI during nighttime surveys (3 adults, 2 gulls of unknown age class), and 2 gulls only were detected during daytime surveys (1 adult, 1 of unknown age class).

Nine radio-tagged gulls never were detected at ANI. Seven of these birds were located only during daytime surveys at other sites. It is possible that they were using roost sites located outside of the study area for roosting at night, however, five of these birds only were heard during one survey. It is possible, therefore, that these birds were roosting within the study area, but lost their transmitters, thus were not detected on subsequent surveys. The remaining two gulls (unknown age class) that were not detected at ANI were detected during night and daytime surveys. All detections of these gulls occurred greater than 16 km away from ANI. Only one other gull was detected greater than 16 km away from ANI during a nighttime survey, a sub-adult detected near Long Marine Laboratory (36° 56' N, 122° 3' W), approximately 25 km from ANI). This gull (A27) also was detected at ANI during 2 of 4 nighttime and 3 of 6 daytime surveys. The only other sites where gulls were detected during nighttime surveys were the Santa Cruz Landfill, cliffs or beaches located near Long Marine Lab, and New Brighton State Beach.

During the 2008 breeding season, three radio-tagged gulls (A16, A42, and A43) were observed visually on ANI. An additional adult gull (A50), which was released without a radio-tag, also was visually observed on ANI and fledged 2 chicks during 2008.

The four adult gulls that were visually observed on ANI during 2008 (A16, A42, A43, and A50) returned to ANI to breed during 2009, and used the same territories held during 2008. During 2009, A42 raised 2 chicks, A43 raised at least 1 chick, and A50 raised at least 2 chicks. Additionally, as of the start of the 2010 breeding season, A42 was prospecting the same territory it held during 2008 and 2009.

An aerial survey was flown on 4 September 2008, after all chicks were expected to have fledged (P. Morris, pers. comm.) to locate gulls that had moved out of the study area after fledging. Two radio-tagged gulls were detected during the flight, both of which were observed on ANI during the 2008 breeding season, and returned to ANI during 2009 to breed. One gull (A42) was detected in Moss Landing, approximately 60 km southeast of ANI (Fig. 1). This gull had been detected on ANI during all daytime and nighttime surveys conducted during 2008, before the aerial survey. The second bird (A16) was detected on ANI during the aerial survey, but neither bird was detected on 23 September. Because both birds were observed on ANI during 2009 without a radio-tag, these birds either were outside the study area on 23 September, had shed their radio-tags, or batteries powering the tags were dysfunctional before the final survey.

Harness Retention

During 2009, 40 radio-transmitters were deployed on Western Gulls captured on beaches at Scott (n=16) and Waddell (n=24) Creeks (Table 2). Five tags were deployed on subadults (n=4) or juveniles (n=1), whereas the remaining tags were deployed on adult Western Gulls. Of the 40 gulls tagged, 34 were detected after release. All birds that

never were detected after release (n=6) had tags attached using neoprene harnesses (1 juvenile, 5 adults). Only one gull with a Teflon-suture harness was not detected again after release, and all gulls with Teflon harnesses attached using metal J-clips were detected again after release.

Table 2. Number of Western Gulls handled by age class (2009). Birds listed as radio-tagged received trail-mounted radio transmitters and identifying leg bands; gulls listed as banded received identifying leg bands only.

Age class	Banded Only	Teflon Harness	Teflon-Suture Harness	Neoprene Harness	Unknown Harness Type
Juvenile	25	0	0	2	0
Subadult	0	0	0	4	1
Adult	3	12	3	16	2
Total	28	12	3	22	3

For the 34 gulls detected after tagging, the average time between tagging and last detection was 152 days (SD=105 days). The shortest interval between tagging and the last date detected was 4 days (neoprene harness). The greatest duration a tag remained functional and attached to a bird was greater than 351 days post-tagging (neoprene harness on B19, visually observed on ANI, 28 April 2010). Of the gulls detected after tagging, 15% (n=5) were detected for the last time ≤45 days post tagging (Fig 4). By 99 days post tagging, 40% of gulls had been detected for the last time. Twenty-one gulls still were being detected >100 days post-tagging (Fig. 4). Between 100 and 200 days post-tagging, an additional 30% of gulls (n=10) were detected for the last time. By 16 October, 155 days post-tagging (May captures) and 230 days post-tagging (February captures) when analysis of DCC data was concluded, only 7 of the 33 gulls were still being detected. The last date of detection indicated that a gull either 1) shed the tags

through failure of the harness, 2) vacated the study area, 3) the battery on the tag failed, or 4) the gull died.

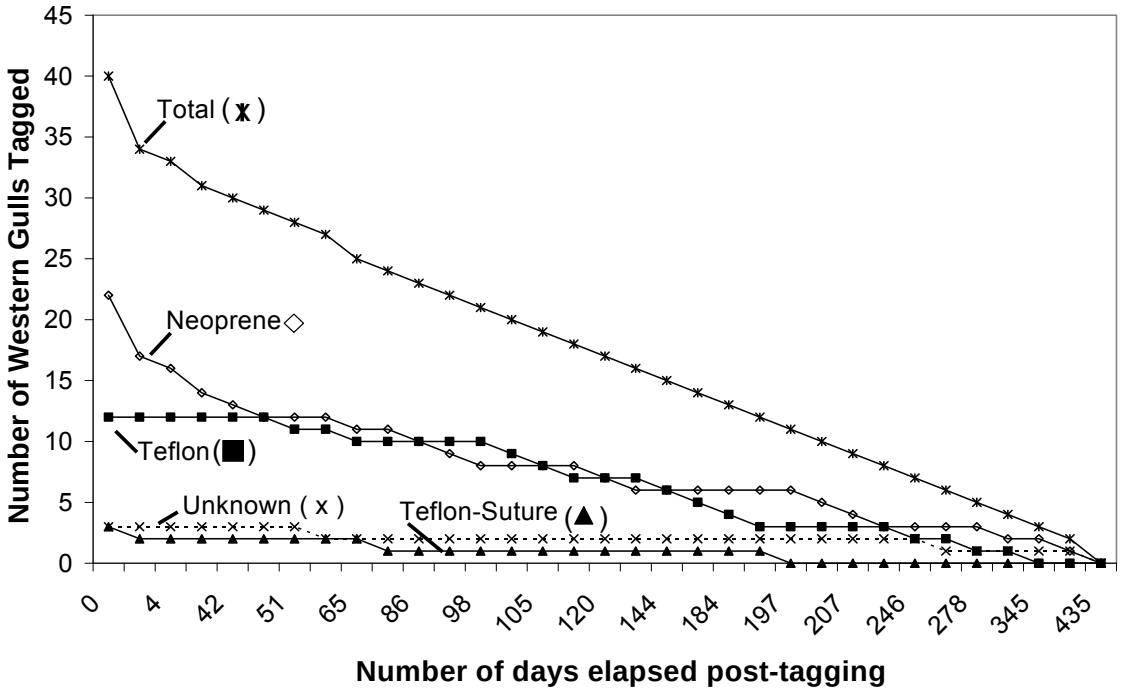

Figure 4: Number of Western Gulls remaining tagged by harness type with time elapsed post-tagging

Three gulls were observed entangled in neoprene harnesses during the course of the study. Entanglement caused death of at least one and possibly as many as five gulls. Two neoprene harnesses with radio-tags were recovered from gulls found dead at Waddell Creek, on 1 April 2009 (35 days post-tagging) and 18 August 2009 (98 days post-tagging). The first bird was in a state of advanced decomposition and scavenged when recovered, so it was not possible to determine cause of death. The second bird had its beak caught in the neoprene harness, and cause of death was attributed to entanglement in the harness. One radio-tag was recovered when it was confiscated from

a transient by Santa Cruz Harbor staff during July 2009. The Teflon ribbon that attached the tag to the neoprene harness had been cut, so the bird probably was dead when the tag was removed. A fourth gull was visually observed in Half Moon Bay 65 days post-tagging, with part of its neoprene harness wrapped around its beak. It is unknown whether this bird was able to rid itself of the harness or died because of the entanglement. The gull which retained a functioning tag for the greatest duration post-tagging (B19, >351 days) also likely died as a result of entanglement in a neoprene harness. This gull was observed on 8 June 2009, with a torn neoprene harness, however the radio-tag was still attached to the harness and hanging across the gull's breast. Several unsuccessful attempts were made to catch the gull and remove the harness. Despite the broken harness, the gull raised 2 chicks on ANI during 2009, and movements observed by radio-tracking were similar to movements of gulls with intact harnesses. This gull returned to ANI for breeding during 2010, and was observed incubating 3 eggs on the same territory it occupied during 2009. On 4 June 2010, B19 was observed for the last time. The radio-tag was no longer attached to the harness; however, a part of the harness was looped over the bird's beak. The bird did not return to the nest, and on 15 June 2010, the nest was abandoned. It is likely that the bird died as a result of entanglement in the harness, causing its mate to terminate incubation. Two Teflon harnesses with radio-tags were recovered from Año Nuevo State Reserve. These harnesses had broken at wear points, indicating that they probably were shed by birds while alive.

Use of Scott and Waddell Creeks

Radio-tagged Western Gulls were detected by automatic data collection systems at Scott and Waddell Creeks throughout the entire study period. Tagged gulls, however, exhibited individual variation in their use of Scott and Waddell Creeks and their associated beaches (Fig. 5). The DCC at Waddell Creek failed to collect data from 3 March to 24 March, therefore, these dates were excluded when comparing attendance patterns of tagged Western Gulls among sites.

Chi-square contingency table analysis was used to determine whether detections of tagged gulls at Scott and Waddell Creek by DCCs were independent of the watershed where the birds were captured. Birds that were detected 0 - 25 times by both DCCs were considered to use neither site or be rare at both sites (neither/rare, Table 5). A gull was considered to use both Waddell and Scott Creeks if it was detected > 25 times and 40% - 60% of detections occurred a one site (Both, Table 5). Birds detected greater than 25 times that had ≥ 60% of detections at one site were classified as using either Scott or Waddell Creeks (Scott or Waddell, Table 5); for example, if 61% of detections of a gull occurred at Scott Creek, and 39% of detections occurred at Waddell Creek, the gull was classified as primarily using Scott Creek. A gull was considered to use both Waddell and Scott Creeks if it was detected > 25 times and 40% - 60% of detections occurred a one site (Both, Table 5). All detections of an individual gull recorded by the DCCs were used to classify how that bird used each watershed.

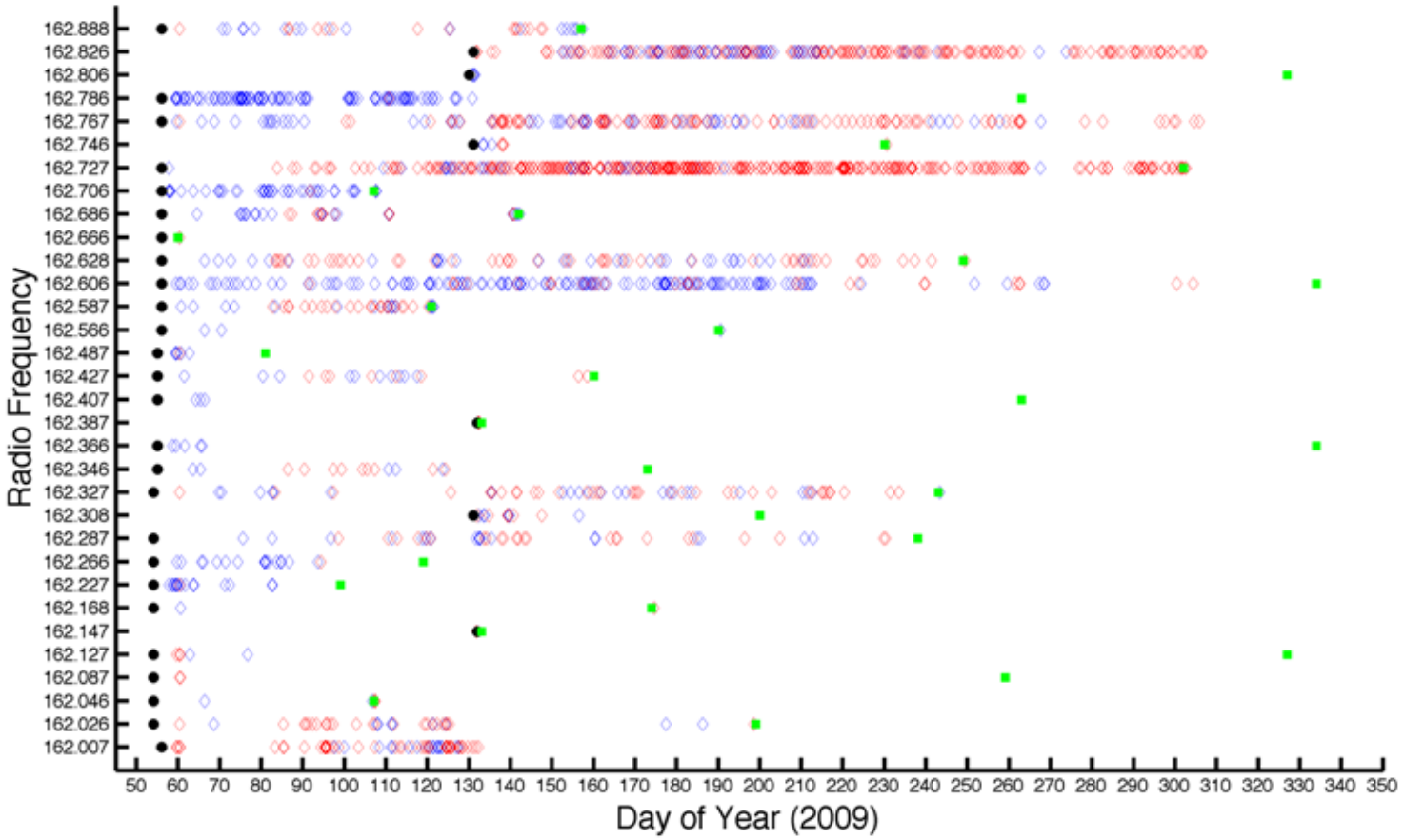

Figure 5: Detections of radio-tagged Western Gulls at Scott Creek (blue) and Waddell Creek (red), plotted with date tagged (black closed circle) and last date detected (green square). Day of the year is plotted on the x-axis, individual radio-frequencies are on the y-axis.

Table 3. Classification of radio-tagged Western Gulls based on attendance at Scott and Waddell Creeks. Neither/rare = fewer than 25 detections at both sites combined, Scott Creek = detected > 25 times with ≥ 60% of detections at Scott Creek, Waddell Creek = > 25 times with ≥ 60% of detections at Waddell Creeks, Both = 40%> x < 60% detections occurred at both sites.

	Tagging Location		
Site Classification	**Scott Creek**	**Waddell Creek**	**Total**
Neither/Rare	10	10	20
Scott Creek	3	2	5
Waddell Creek	2	4	6
Both	1	2	3
Total tagged at each site	16	18	34

Of the 34 gulls detected after release, three were categorized as using Scott and Waddell Creeks (8.8%). Five gulls (14.7%) were categorized as using primarily Scott Creek, whereas six gulls (17.6%) were categorized as using primarily Waddell Creek. The majority of gulls (58.8%) were categorized as using Scott and Waddell Creek either never or rarely (≤25 total detections at both sites combined). Based on Chi-square contingency table analysis, attendance of tagged Western Gulls at Scott and Waddell Creeks, (as defined by detections on DCCs placed at each creek mouth) was independent of site of capture ($\chi^2(3,N = 34)$ $p > 0.05$). This means that birds captured and tagged at Waddell Creek were no more likely to be detected at Waddell Creek than birds captured at Scott Creek. Conversely, gulls captured and tagged at Scott Creek were no more likely to be detected at Scott Creek than birds captured at Waddell Creek. It was possible,

therefore, to combine data from gulls tagged at both sites in analyzing patterns of attendance at Scott and Waddell Creeks.

To examine patterns of use at Scott and Waddell Creeks based on detections recorded by DCCs, it was necessary to account for tags lost throughout the study period. This was done by dividing the number of birds detected by DCCs at Scott and Waddell Creeks on a given day by the number of gulls available for tracking on that day. The last date a gull was detected before the date a carcass or radio-tag was recovered, or the last date a gull was detected (if a carcass or tag was not recovered) was used as the last date a gull was available for tracking. The resulting proportions were used to test the hypothesis that attendance at Scott and Waddell Creeks varied by site and phase of the breeding cycle, using a one-way, Model I ANOVA. Data were moderately auto-correlated (Durbin-Watson D statistic = 1.437), so only data from every other day were included in the analysis, which removed the problem of autocorrelation (Durbin-Watson D statistic = 1.831). Sample sizes (number of days in each phase of the breeding cycle) were not equal, so Levene's test was used to test the assumption of equal variances. Untransformed data did not meet assumptions of equal variances and normality, so an arcsine transformation was used, because data were proportions. After transformation, data still were moderately non-normal (One-sample Kolmogorov-Smirnov test, P = 0.094), but error variances were still non-equal. Because analysis of variance is robust to deviations from equal variance and normality (Underwood 1981), untransformed data were used in this analysis. A significant site by season interaction was observed (Table 6), indicating that use of the two sites (Scott and Waddell Creeks) by radio-tagged Western Gulls differed throughout the study period (Fig. 6). When the post-fledging

period was excluded from analysis, there was no significant effect of season (Table 6), but the mean number of birds detected per day (relative to the number of gulls tagged) was significantly greater at Waddell Creek than at Scott Creek (Fig. 6).

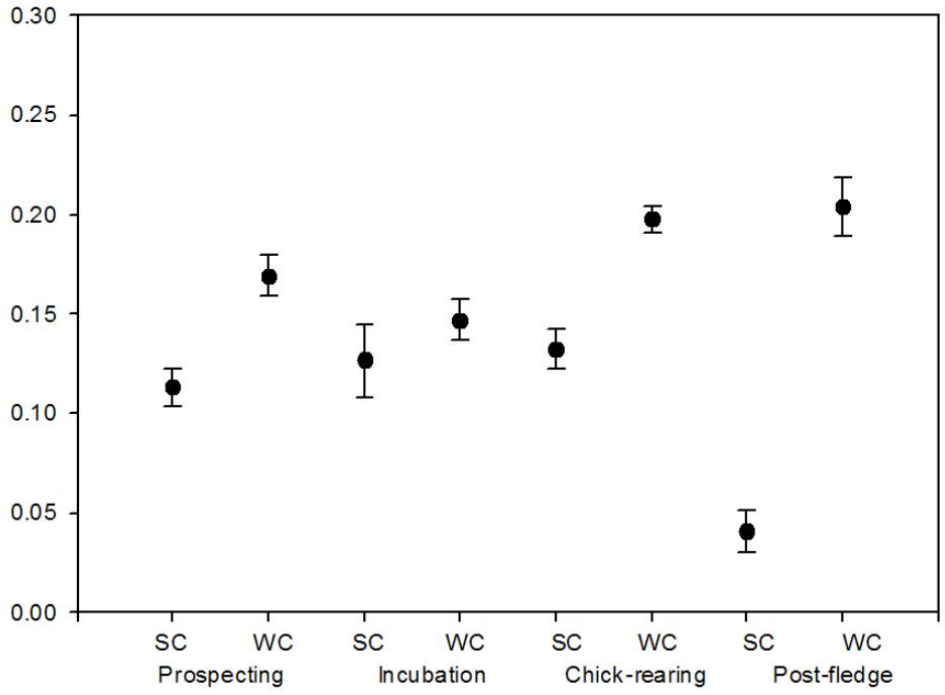

Figure 6. Mean % (± SE) of gulls attending Scott Creek (SC) and Waddell Creek (WC) throughout four phases of the breeding cycle (Prospecting, Incubation, Chick-rearing, and Post-fledge phases), based on DCC detections. Data were standardized by dividing the number if gulls detected per day by the number still in the tagged population to that date.

Table 4. Two-factor ANOVA comparing attendance of Western Gulls at Scott and Waddell Creeks during: A) four phases of the breeding cycle (Prospecting, Chick-rearing, Incubation, and Post-fledging) and B) the first three phases of the breeding cycle (Prospecting, Chick-rearing, Incubation)

	Source	Sum of Squares	Degrees of Freedom	Mean Square	F-Ratio	P-value
A.	Site	0.215	1	0.215	27.061	0.000
	Season	0.069	3	0.023	2.9	0.036
	Site*Season	0.174	3	0.580	7.323	0.000
	Error	1.554	196	0.008		
B.	Site	0.042	1	0.042	6.734	0.010
	Season	0.018	2	0.009	1.394	0.252
	Site*Season	0.018	2	0.090	1.425	0.246
	Error	0.889	140	0.006		

The distribution of detections (Fig. 7) during the course of the 24-hour period did not differ significantly between Scott and Waddell Creeks during the prospecting phase (Two-Sample KS Test, $p = 0.840$), incubation phase (Two-sample KS test, $p = 0.109$), or chick rearing phase (Two-Sample KS Test, $p = 0.840$) of the breeding cycle. The distribution of detections during the course of the 24-hour period did differ significantly between the two sites during the post-fledging period (Two-Sample KS Test, $p = 0.001$). The majority of detections occurred during daylight hours during all phases of the breeding cycle (Fig. 7). During the prospecting phase, 95% of detections at Waddell Creek and 64% of detections at Scott Creek occurred between 0500 and 1900 hours. During the incubation phase, 89% of detections at Waddell Creek and 98% of detections at Scott Creek occurred between 0500 and 1900 hours. During the chick-rearing phase, gulls were detected 24 hours of the day at both sites. Gulls were detected during all hours of the day at Waddell Creek during the post-fledging period, however, at Scott Creek 100% of detections occurred between 0600 and 1800 hours.

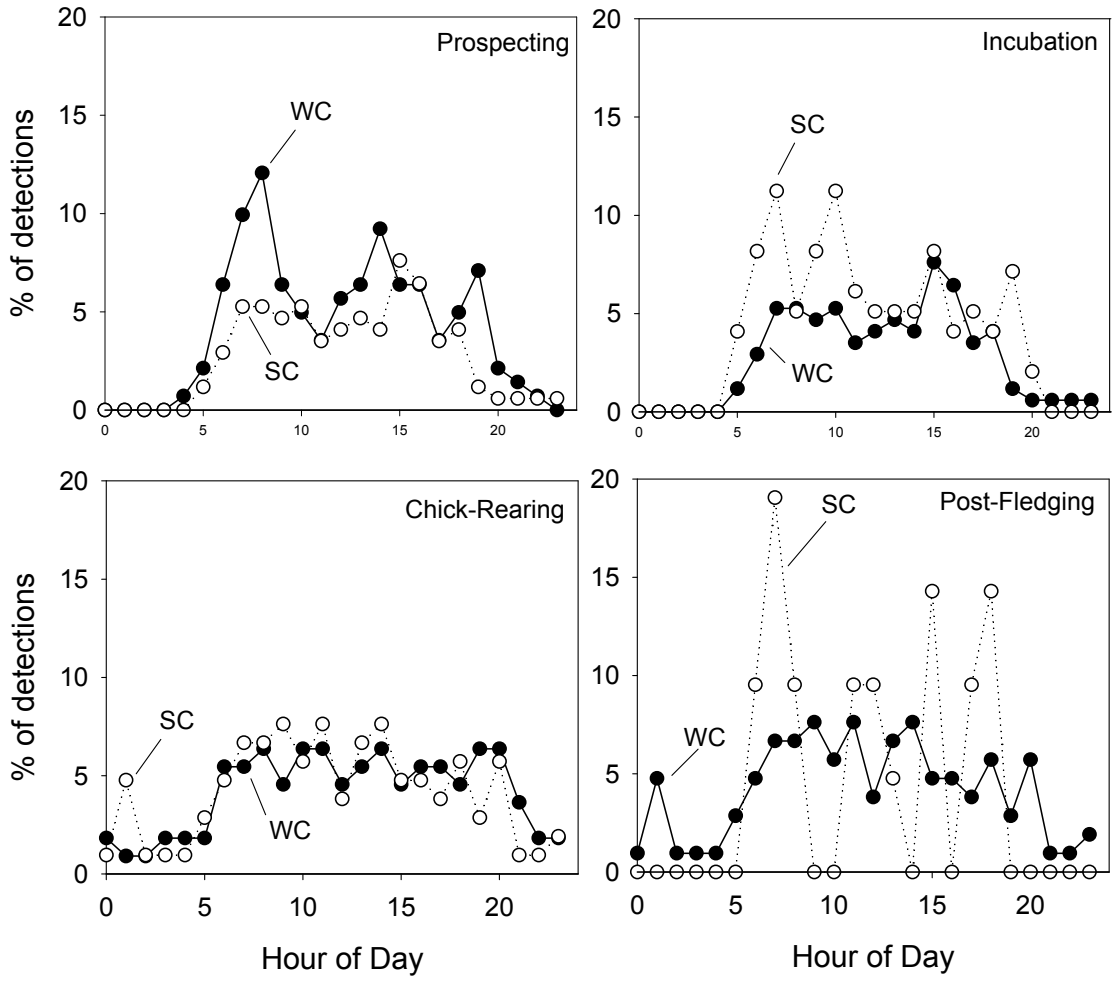

Figure 7. Percentage of detections of radio-tagged Western Gulls throughout the 24-hour period during each phase breeding cycle (2009): Prospecting, Incubation, Chick-rearing, and Post-fledge for Waddell Creek (WC; filled circle, solid line) and Scott Creek (SC; open circle, dashed line).

Juvenile salmonids were classified as having migrated out of the Scott Creek system and into the ocean if they were detected by an instream PIT tag antenna located approximately 100 m upstream of the creek mouth, and not detected subsequently by the same antenna before lagoon closure. Detections of juvenile salmonids by the instream reader occurred consistently until the end of May, and 98% of detections occurred by 18 June (Fig. 8). It is important to note that these data do not include the entire smolt migration period, which may begin as early as the lagoon opens in December (Hayes et al., in review). Greatest smolt outmigration during the period that the PIT tag antenna was operational (75% of all detections) occurred between 26 March and 21 April 2009. The majority of detections (90%) occurred during the night, with only 10% of detections occurring between 0600 and 1800 PST. On 30 March, the instream PIT tag reader detected 376 uniquely tagged salmonids, representing 26% of the total detections. This coincided with a release of 995 steelhead from a small conservation hatchery that operates within the Scott Creek watershed. To determine whether the inclusion of detections from 30 March biased the time of day during which outmigration occurred, detections from 30 March were removed from the analysis, and the resulting distribution tested against the original distribution including data from 30 March. The distribution of tags detected across the 24 hour period did not change significantly when detections from March 30 were removed from the analysis (2-Sample KS Test, $p = 0.980$). Detections that occurred on 30 March, therefore, were included in all subsequent analyses.

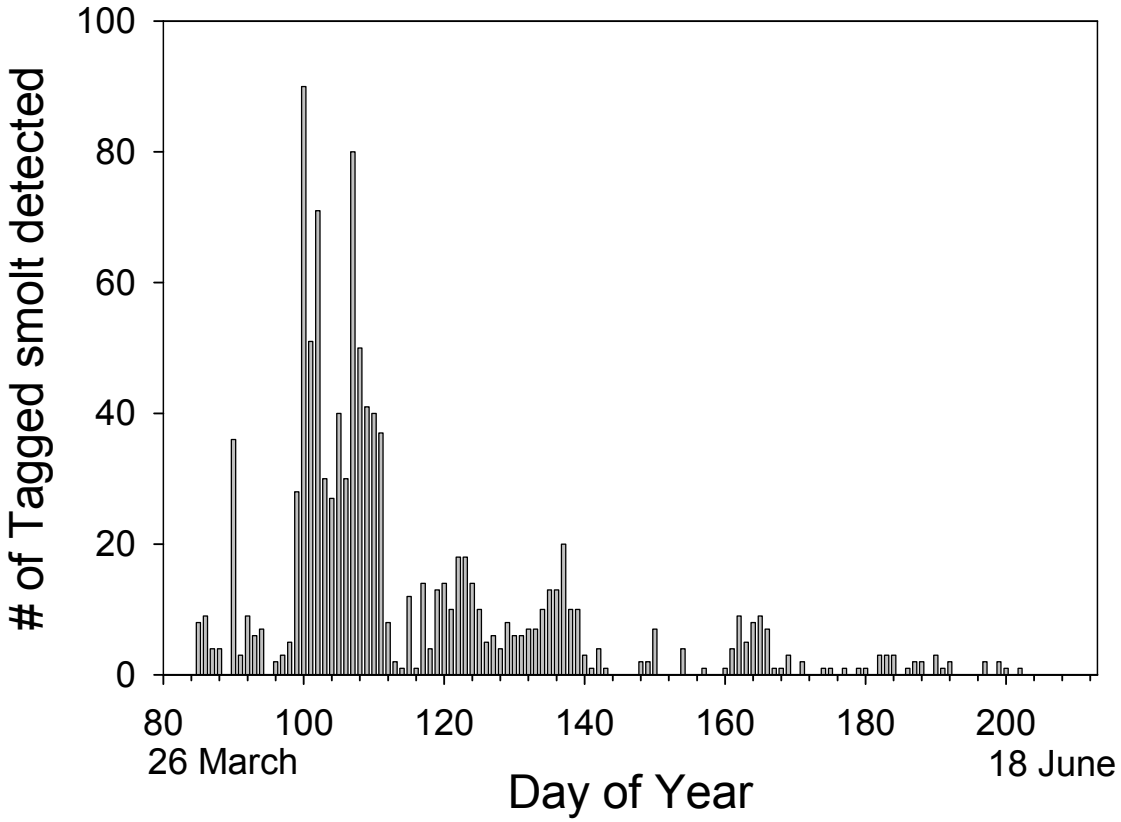

Figure 8: Number of PIT-tagged outmigrating salmonid smolt per day, detected by an instream PIT tag antenna installed 100 m upstream of the Scott Creek mouth, between 26 March and 18 June. Detections on 30 March (376 detections) are not included in figure

There was minimal overlap between presence of radio-tagged Western Gulls at the Scott Creek mouth, and movement of tagged juvenile salmonids out of Scott Creek and into the ocean (Fig. 9). Detections of gulls primarily occurred during daylight hours, and outmigration of juvenile salmonids occurred at night (March 26-April 21). Ninety percent of birds were detected between 0600 and 1800 PST, whereas 10% of fish were detected between 06:00 and 18:00 PST. During this time period, length of day was

relatively constant: sunrise ranged from 0603 PST on 26 March to 0527 PST on 21 April and sunset ranged from 1826 PST on 26 March to 1848 PST on 21 April (Fig. 9).

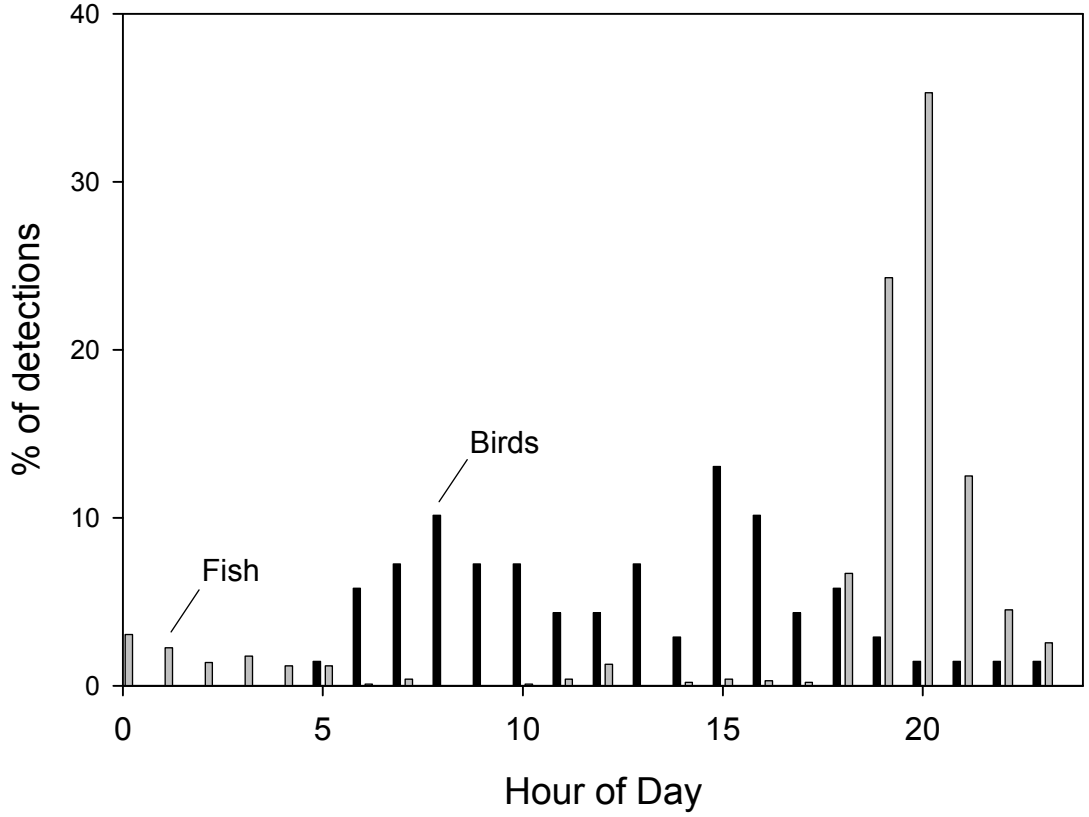

Figure 9: Percentage of gulls detected at Scott Creek per hour and percentage of PIT-tagged outmigrating salmonid smolt detected per hour by an instream PIT tag antenna installed 100 m upstream of the Scott Creek mouth during greatest smolt outmigration (26 March to 21 April). Daylight hours are denoted with a solid line.

Movements of Adult Western Gulls

During 2009, 24 surveys were conducted by car between 23 March and 30 October. These surveys spanned the Western Gull breeding season, and included part of the smolt outmigration period. Because surveys were conducted once every 7 to 14 days, only three surveys occurred during the incubation period (May 1 to June 3). In analyzing data from active tracking, therefore, data from the incubation period were combined with surveys conducted during the prospecting phase of the breeding cycle (1 March-30 April). For the following analyses, this time period is referred to as the "pre-hatch period" (March 1-June 3, n = 8 surveys). Surveys were conducted during day (n=7) and night (n = 1) during the pre-hatching period. During the pre-hatch period, the mean percentage of birds (standardized by the number available for tracking on a given date) detected at ANI was ($\bar{x} = 6.6, SE = 1.6$). The only other site that had a greater percentage of birds detected was the Santa Cruz Landfill, which was located 25.5 km away from ANI ($\bar{x} = 9.2, SE = 3.2$). A decreasing trend was observed in the percentage of birds detected per site with increasing distance from ANI, with the exception of the Santa Cruz landfill (Fig. 10, pre-hatch).

Nine surveys (7 daytime, 2 nighttime) were conducted during the chick-rearing period (4 June to 15 Aug). The same general trend of decreasing percentage of birds detected with increasing distance from ANI was observed (Fig. 10, chick-rearing). A greater percentage of birds were detected at ANI during the chick-rearing period ($\bar{x} = 12.6, SE = 3.5$) than during the pre-hatch period. Conversely, the percentage of gulls detected at the landfill was less during the chick-rearing period ($\bar{x} = 4.6, SE = 2.0$) than

the pre-hatch period. The percentage of gulls detected at two sites, Natural Bridges (NB, 30.4 km from ANI) and the San Lorenzo River (SLR, 33 km from ANI), were greater than the percentage of gulls detected at the landfill during the same period. Tracking was not conducted at NB during the pre-hatch period, so no comparison can be made between these two periods at this site. The percentage of gulls detected at SLR, however, was greater during the chick-rearing period ($\bar{x} = 10.3, SE = 1.4$) than during the pre-hatch period ($\bar{x} = 4.3.5, SE = 0.6$) . The majority of detections at SLR were attributed to two gulls, which were detected consistently during the chick-rearing period. The radio-tag from one of these birds was recovered, and it is unclear how many detections of this bird were actual detections of the gull and how many were detections of the tag after it was lost by the bird. The other bird was visually observed on three occasions and likely was nesting on the Santa Cruz Wharf because it was detected at SLR on all occasions between 10 June and 30 Oct (Gull ID: B38). San Lorenzo River is adjacent to a popular tourist attraction and beach, which provide an alternative source of food for gulls in the area. Also of note is the greater percentage of gulls detected at Waddell Creek during chick-rearing (Fig. 10), which served as the closest site to ANI for bathing and drinking in freshwater.

Six surveys (5 daytime, 1 nighttime) were conducted during the post-fledging period (Aug 16-Oct 30). The greatest change during this period was the near absence of detections at ANI (Fig. 10, Post-Fledge). The greatest percentage of detections occurred at the Santa Cruz landfill ($\bar{x} = 7.3, SE = 3.36$) , Natural Bridges $\bar{x} = 18.1, SE = 3.4$) , and San Lorenzo River ($\bar{x} = 7.7, SE = 1.8$) . Detections of gulls at SLR were again driven by

the presence of individual B38. Five individuals were detected at NB during the post-fledge period, of note are two birds (B18 and B90) that were not detected away from ANI or Waddell Creek until the post-fledging period.

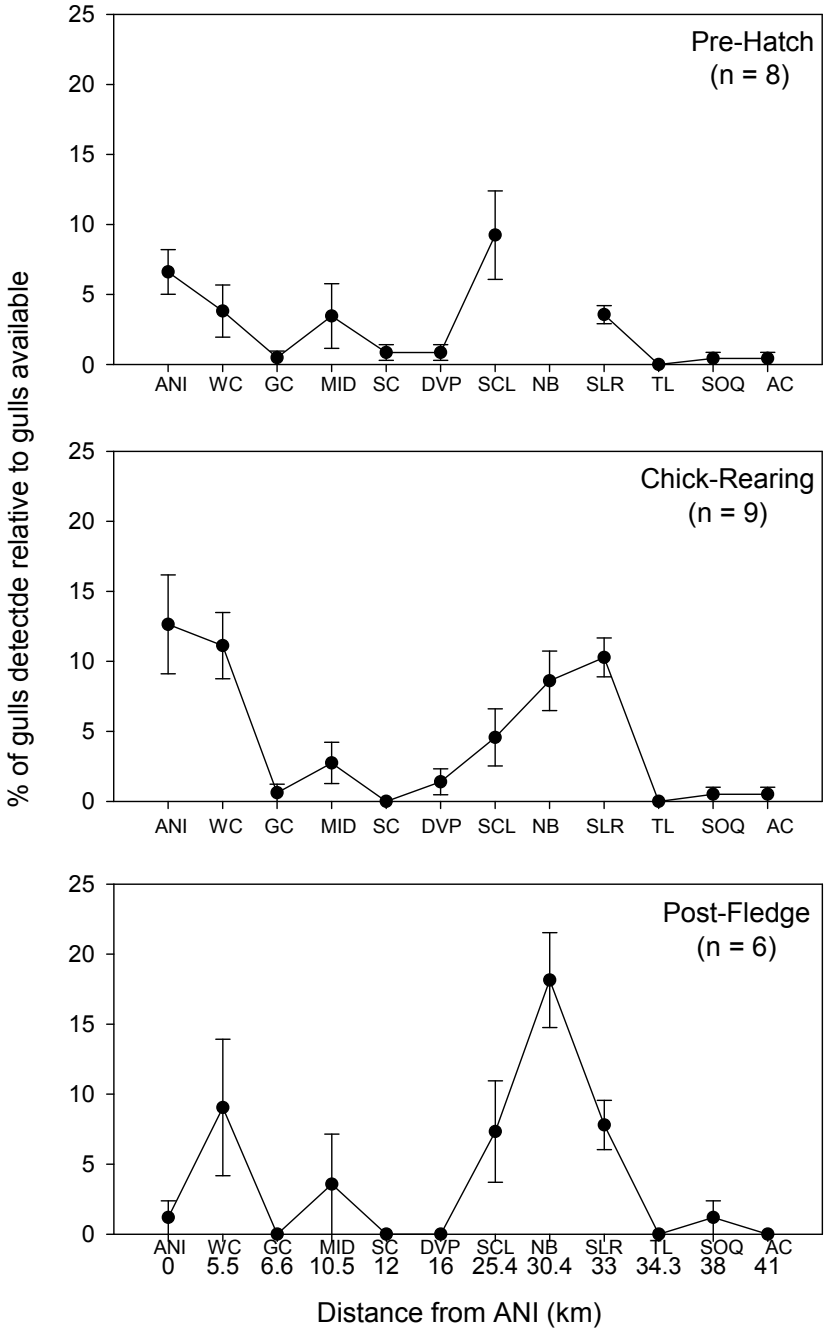

Figure 10: Mean number of radio-tagged Western Gulls (± SE) detected with increasing distance (km) from ANI during 2009. Data are presented as percentage of the total number of gulls available for tracking on a given date during three phases of the breeding cycle (pre-hatch, chick rearing, and post-fledge). Locations where gulls were tracked are abbreviated as follows: Año Nuevo Island (ANI), Waddell Creek (WC), Gazos Creek (GC), Middle (MID), Scott Creek (SC), Davenport (DVP), Santa Cruz Landfill (SCL), Natural Bridges (NB), San Lorenzo River (SLR), Twin Lakes (TL), Soquel Creek (SOQ), and Aptos Creek (AC)

During the 2009 breeding season, 14 radio-tagged Western Gulls (all adults) were detected using ANI during active radio tracking. Four of these birds were detected during the June aerial survey, during the period when gulls were rearing chicks. No gulls were detected on ANI during the September aerial survey, after chicks had fledged. Of the 14 gulls detected on ANI during 2009, 8 were visually observed on the island, 2 of which were observed raising 2 chicks, indicating that tagging did not affect the ability of these birds to breed, despite the damaged status of the harness of one of the birds (B19, described previously). Only one juvenile Western Gull, which had been banded but not radio-tagged, was seen at ANI during 2009. This bird was observed on the lower, intertidal portion of the island, scavenging a pinniped carcass. It was not observed on the main breeding colony. Ten gulls that were observed at ANI also were detected foraging at the Landfill in Santa Cruz. Eighteen radio-tagged Western Gulls were detected foraging at the landfill during 2009. Of the 8 gulls detected at the landfill but not detected at ANI, one was detected at the landfill only. Six gulls that were detected at the landfill but not at ANI were detected by DCCs at Scott and Waddell Creeks.

Eighteen gulls were detected during the June aerial survey, and 12 were detected during the September aerial survey. All gulls detected in September were detected in June. Greater than 50% (n=7) of the gulls detected during both surveys were in the same location. One gull (B58) was detected in the same location during all ground surveys following the June aerial survey and either died or shed its harness (the tag was localized to a steep cliff, so it was not possible to attempt to recover the tag). All other birds detected during the September aerial survey retained their tags and were alive because

they were detected at different locations during ground surveys conducted after the September aerial survey. Three gulls were detected outside of the main survey area during aerial surveys conducted during 2009. One gull (B50), which was observed on ANI visually and during radio-tracking surveys, was detected at the Watsonville Landfill during the June aerial survey. This was the greatest documented distance travelled by a gull using ANI during the 2009 breeding season. This same gull was detected near Soquel (38 km from ANI) and Aptos (41 km from ANI) Creeks during active tracking surveys. Only one other gull was detected at these sites during the study period. One gull was detected in Monterey CA, during the June aerial survey only. This bird was a juvenile tagged with a neoprene harness in May 2009 (Gull ID B02), and may have vacated the study area, shed its harness, or died. The other gull that was detected outside of the main study area was detected near the mouth of the Salinas River during both aerial surveys. This gull (A85) was an adult tagged with a neoprene harness during February. This bird may have been using Scott Creek as a loafing area before dispersing to a breeding area south of the main study area. This gull was not located on both attempts following the aerial surveys, so it is not thought to have shed its tag or died.

PIT Tag Scanning: Southeast Farallon Island

Despite scanning all the main areas used by Western Gulls for breeding and roosting, only one PIT tag was detected on SEFI, in an area used by Common Murres and Brandt's Cormorants. The tag was from a steelhead tagged in Scott Creek during November 2005, and had a fork length of 209 mm and a mass of 101.9 g when it was

handled. Along with receiving a PIT tag, the fish also was tagged with a temperature logger (Hayes et al. in press).

DISCUSSION

Aside from ANI, the main sites where gulls were detected roosting during nighttime radio-telemetry surveys were either steep cliffs or beaches. The cliff areas could not be scanned due to lack of accessibility. One attempt was made to scan for PIT tags on a beach on the mainland near ANI. Despite known use of this site by juvenile and adult Western Gulls as both a day and night roost, no PIT tags were detected. While scanning for PIT tags on this beach, I recovered the radio-tag of a gull that had been detected on ANI, therefore, this beach also was used by at least one of the radio-tagged gulls. This attempt indicated that the dynamic nature of beaches make them unsuitable for PIT tag scanning, because tags either were buried too deep to be detected or washed away by daily tidal cycles.

Southeast Farallon Island provides breeding habitat for nearly 11 times more Western Gulls than does ANI, however, SEFI is located 100 km north of Scott Creek, whereas ANI is located 12 km north. Competition for breeding space on SEFI is intense (Pierotti 1981), and adults begin reoccupying territories during November and December (Spear 1988). Because foraging ranges of Western Gulls during the breeding season may be up to 80 km (Spear 1988), Western Gulls breeding on SEFI were not likely travel to Scott Creek for foraging. Consumption of juvenile salmonids originating in streams in Santa Cruz and San Mateo counties by Western Gulls using SEFI, therefore, would have

to occur in the ocean. Although juvenile coho and steelhead are highly surface oriented, travelling in the top 30 to 60 m of the water column (Walker et al. 2000), they may be too deep to be caught by surface-picking or shallow plunge-diving Western Gulls, but not too deep for diving birds like Common Murre's or Brandt's Cormorants (Ashmole 1971, Hunt and Hunt 1976). Much of the area of SEFI used for breeding by Western Gulls is vegetated, whereas the Murre/Cormorant breeding area where the one tag was located is guano- covered rock, which is similar to the substrate at ANI. It is possible that PIT tag detection in gull colonies on SEFI could be affected by presence of vegetation. Additionally, salmonids travelling past SEFI include not only coho and steelhead from south of the Golden Gate, but also salmonids travelling out of the San Francisco Bay (Chinook, *Oncorhynchus tshawytscha,* and steelhead). The larger number of juvenile salmonids moving out of the bay could dilute the effect of predation of fish from small central California coastal streams by seabirds nesting on SEFI. Additionally, predation of salmonids from the San Francisco Bay would go undetected by PIT-tag scanning, as they rarely are PIT-tagged. Salmonids, however, have not been reported in diet of Western Gulls breeding on Alcatraz Island, San Francisco County, California (Annett and Pierotti 1989, 1999) Southeast Farallon Island (Spear 1993), or Santa Barbara Island (Hunt and Hunt 1976). Año Nuevo Island may represent a unique case where 1) the percentage of PIT-tagged salmonids is great, 2) salmonids are accessible to gulls as they migrate through shallow, clear streams and 3) predation occurs in close enough proximity to a large breeding colony that is accessible for scanning for PIT tags.

There was considerable individual and seasonal variation in use of the study area by radio-tagged Western Gulls. Año Nuevo was the primary breeding site used by Western Gulls radio-tagged during this study. During the pre-hatch and chick-rearing periods of the breeding cycle, the majority of gulls were detected between ANI and the Santa Cruz Landfill. The high frequency of detections at the San Lorenzo River (SLR) was driven by one gull that was consistently detected at the Santa Cruz wharf, which is adjacent to SLR. Because the Santa Cruz wharf serves as a breeding site for Western Gulls (Spear et al. 1986) and this gull was not observed away from the wharf until after the post-fledge period, it probably was breeding at the wharf.

After fledging, the number of Western Gulls detected at ANI decreased markedly. These results are in accordance with Western Gull attendance patterns at SEFI. Spear (1988) found attendance at the breeding colony on SEFI was greatest in April, corresponding to the start of egg-laying, and adults dispersed following fledging of chicks, between August and September. These results indicate that adult Western Gulls breeding at ANI were acting as central place foragers during the breeding season, and dispersed following the breeding season.

Data from active tracking and DCCs installed at Scott and Waddell Creeks indicated that individual birds exhibited fidelity to foraging and loafing sites. Although the change made to the scanning frequency of the DCCs mid-study could have increased the probability that a gull was detected at a given site, it is unlikely to have biased the results of the study, because it is unlikely for a gull to be missed using either sampling interval (7 or 15 minutes). It is possible that a gull could have been detected if it

happened to be flying past the DCC during the 10 seconds that the DCC was actively listening for its tag, however, the probability of this occurring was low. Additionally, a gull could land within range of the datalogger and leave again within the period of time that the DCC was not listening for that bird. However, such a bird would be ecologically irrelevant given the objectives of this study; a gull that spends less than 7 min at Scott or Waddell Creek was probably no more likely to eat a salmonid than a bird that spends less than 15 min at the same site.

Tagged Western Gulls could be categorized as routinely using Scott Creek, Waddell Creek, both locations, or neither location. Scott and Waddell Creeks provided sources of freshwater, and gulls were routinely observed bathing and drinking in the creek/lagoon. Western Gulls also used beaches adjacent to Scott and Waddell creeks for loafing, and moved to intertidal habitat for foraging during low tides. Site fidelity to foraging sites has been demonstrated for a variety of larids, including Black-legged Kittiwakes, *Rissa tridactyla* (Irons 1998), Herring Gulls, *Larus argenteus* (Morris and Black 1980), Olrog's Gulls, *L. atlanticus*, (Yorio et al. 2004), and Western Gulls (Spear 1988). Site fidelity to foraging areas increases foraging efficiency (Morris and Black 1980, King et al. 1995, Irons 1998, Yorio et al. 2004, Bugoni et al. 2005). Returning to sites that are productive can shorten foraging trip duration, because birds already know where to find food (Morris and Black 1980, King et al. 1995, Irons 1998, Yorio et al. 2004, Bugoni et al. 2005).

Seventy-one percent of the gulls that used ANI during the 2009 breeding season also were detected foraging at the dump during the study period. The number of tagged

gulls detected at the dump decreased during the chick-rearing period (compared with the pre-hatch and post-fledging periods). This decrease in use of the dump may signal a switch in diet in response to the chicks hatching. Annett and Pierotti (1989) demonstrated that Western Gulls nesting on Alcatraz Island switched their diet from garbage to fish when chicks hatched. They suggested that adults forage on garbage before chicks hatch because it is a reliably accessible food source, but energy requirements of chicks cause them to switch to a more nutritious but less reliable food source. Spear (1988) also reported Western Gulls breeding on SEFI fed in oceanic habitat during the breeding season, but dispersed to coastal landfills in August and September, after chicks fledged. Chick-hatching, and the corresponding decrease in dump use by radio-tagged gulls occurred after the peak smolt outmigration, so it is unlikely that adults Western Gulls switched from feeding at the dump to feeding on juvenile salmonids at this point in the breeding cycle. One radio-tagged Western Gull was detected at ANI during active tracking and offshore during both aerial surveys conducted during 2009 (23 June and 17 September), indicating at least some feeding offshore by members of the ANI breeding population of Western Gulls. During active tracking and aerial surveys, radio-tagged Western Gulls often were detected in intertidal and near-coastal foraging areas.

The number of radio-tagged Western Gulls decreased with increasing distance from ANI during the pre-hatch period and chick-rearing periods, and only two radio-tagged gulls were detected at the two southernmost watersheds within the study area (Soquel and Aptos Creeks). These results indicate that Western Gulls breeding on ANI were acting as central place foragers during the breeding season, and are in agreement

with PIT tag recoveries on ANI. The percentage of tagged salmonids detected on ANI, relative to the number tagged in an individual watershed decreased as distance from ANI increased (Osterback et al. in prep). Only 3 PIT tags from Soquel Creek and no PIT tags from Aptos Creek have been detected on ANI (Chapter 1). Peak smolt outmigration occurred during the phases of the breeding season when Western Gulls breeding on ANI were most tied to breeding territories (prospecting, incubation, and early chick-rearing). Gulls breeding on ANI were less likely to be detected using watersheds south of Scott Creek. Risk of predation by the ANI population of Western Gulls, therefore, was less for salmonids in SLR, Soquel, and Aptos Creeks than for salmonids in Scott, Waddell, and Gazos Creeks. Predation rates were less than 0.35% of all PIT-tagged juvenile salmonids in SLR and Soquel Creek, and 0% for Aptos Creek, but were 0.78% in Scott, 2% in Waddell, and 3% in Gazos Creeks (Chapter 1). Additionally, radio-tagged Western Gulls were detected by DCCs at Waddell Creek more frequently than at Scott Creek during all phases of the breeding cycle, further explaining the difference in the predation rates of salmonids at the two creeks; the predation rate at Waddell Creek was more than double the predation rate at Scott Creek.

Use of Santa Cruz and Watsonville landfills by Western Gulls that bred on ANI supports the hypothesis that the increase in the ANI breeding population is being driven in part by access to food subsidies in the form of human waste. These so-called "subsidized predators" may be released from density-dependent effects, allowing populations to increase independent of prey availability (Gompper and Vanak 2008). When predators are abundant and prey rare, even low levels of predation can negatively

impact or prevent recovery of prey populations (Roby et al. 2003, Sanz-Aguilar et al. 2009).

Because of the proximity of ANI to watersheds where salmonids are easily accessible, predation by Western Gulls was likely to have occurred historically; however, levels of predation of salmonids before anthropogenic food subsidies were available to the ANI population of Western Gulls are unknown. Although direct observation of predation at creek mouths was rare, and minimal overlap occurred between presence of Western Gulls and outmigrating salmonids at daily and seasonal time scales, results of this study indicate that predation may be 100% of all outmigrating salmonids when overlap does occur.

The mismatch in time between fish movements and bird presence at creek mouths is likely a strategy used by outmigrating juvenile salmonids to avoid predation by visual predators (e.g. gulls and other avian species). Because of this mismatch in time between predator and prey, current levels of per capita predation may be comparable with historical levels. The increase in the gull population combined with the concurrent decreases in local salmonid populations, however, has resulted in levels of predation that may be unsustainable when combined with other pressures faced by these imperiled populations.

Western Gulls exhibited site fidelity to foraging and loafing areas, including Scott and Waddell Creek, however there was little overlap between predator and prey at daily or weekly temporal scales. Western Gulls that exhibited site fidelity to Scott and Waddell Creeks, therefore, probably were not specializing on salmonids directly. Instead,

by exhibiting site fidelity to one of these watersheds for loafing, bathing, or use of intertidal foraging habitat, these gulls were probably more likely present during rare occasions when salmonids were available in the lower portions of creeks, allowing them to opportunistically prey on smolts as they migrated from freshwater to ocean habitat. Additionally, Western Gulls breeding on ANI exhibited site fidelity to nesting territories, a behavior common to this species (Spear 1993). Detections of PIT tags on ANI occurred in clusters, and these clusters persisted among years. These clusters of tags probably represent tags deposited in nesting territories by one or both members of a nesting pair, indicating that a few individual gulls may be responsible for the majority of predation.

Fidelity of Western Gulls to these foraging and breeding sites may provide managers with tools for reducing the effect of predation on CCC-coho and CCC-steelhead populations. Sanz-Aguilar et al. (2009) demonstrated that survival of European storm-petrels on an island in the Mediterranean Sea increased substantially when individual Yellow-legged Gulls (*Larus michahellis*), which foraged specifically on petrels, were removed from the island. Their results indicated that removal of "repeat predators" may be more cost-effective and less time- and personnel-intensive than large-scale culling programs, and more palatable to the public than a large-scale culling program. Instead of widespread culling of the ANI breeding colony, therefore, techniques to reduce predation of juvenile salmonids may include 1) identification and removal of gulls using territories where tags consistently were detected, 2) reductions of gulls carried out at the watersheds where predation is greatest (Gazos, Waddell, and Scott), or 3) exclusion of gulls from creek mouths during smolt outmigration.

It must be emphasized that this study was primarily of adult Western Gulls using one breeding colony (ANI). Juvenile Western Gulls were observed catching and eating salmonid smolts with the same efficiency as adults. Because current estimates of predation of CCC-coho and CCC-steelhead smolts by Western Gulls come from recoveries of PIT tags from adults on a breeding colony, estimates presented in this study likely still underestimate predation by Western Gulls by approximately 50%. Several other species of gulls have been observed at Scott and Waddell Creeks, often in great numbers. Although there has been no documentation of predation of juvenile salmonids in central California watersheds by other species of gulls, at least one species (California Gull) preyed on salmonids in the Columbia River Basin (Major et al. 2005). If juvenile salmonids are eaten not only by Western Gulls, but also by other species of gulls, we are further underestimating predation of CCC-coho and CCC-steelhead smolts by gulls by an unknown factor. Additionally, Caspian Terns (*Sterna caspia*) have been observed foraging offshore of Scott and Waddell Creeks, and the San Lorenzo River. Recoveries of PIT tags from a Caspian Tern colony in San Francisco Bay indicate that there is at least some undetermined level of predation of steelhead from Scott Creek by individuals of this species (L. Adrean, pers comm.). Overall, the effects of predation of juvenile coho and steelhead by avian species are likely much greater than the results of this study indicate.

LITERATURE CITED

Ackerman J. T., Adams, J. Y. Takekawa, H. R. Carter, D. L. Whitworth, S. H. Newman, R. T. Golightly, and D. L. Orthmeyer. 2004. Effects of Radiotransmitters on the Reproductive Performance of Cassin's Auklets. Wildlife Society Bulletin 32:1229-1241.

Ainley D. G., D. W. Anderson, and P. R. Kelly. 1981. Feeding ecology of marine cormorants in southwestern North America. The Condor 83:120-131.

Anderson S. K., D. D. Roby, D. E. Lyons, and K. Collis. 2007. Relationship of Caspian tern foraging ecology to nesting success in the Columbia River estuary, Oregon, USA. Estuarine, Coastal and Shelf Science73:447-456.

Annett, C. A., and R. Pierotti. 1989. Chick hatching as a trigger for dietary switching in the Western Gull. Colonial Waterbirds 12:4-11.

Annett, C. A., and R. Pierotti. 1999. Long-term reproductive output in Western Gulls: consequences of alternative tactics in diet choice. Ecology 80:288–297.

Ashmole N. P. 1971 Seabird ecology amd the marine environment. Avian Biology 1:223-286.

Balz D. M., and G. V. Morejohn. 1977. Food habits and niche overlap of seabirds wintering on Monterey Bay, California. The Auk 94:526-543

Belant J. L., T. W. Seamans, S. T. Gabrey and S. K. Ickes. 1993. Importance of landfills to nesting herring gulls. The Condor 95:817-830.

Bjorkstedt E. P., B. C. Spence, J. C. Garza, D. G. Hankin, D. Fuller, W. E. Jones, J. J. Smith, and R. Macedo. 2005. An analysis of historical population structure for evolutionarily significant units of Chinooks salmon, coho salmon, and steelhead in the north-central California coast recovery domain. NOAA-TM-NMFS-SWFSC-382, 231p

Bond M. H., C. V. Hansen, A. Baertsch, S. A. Hayes, and R. B. MacFarlane. 2007. A New Low-Cost Instream Antenna System for Tracking Passive Integrated Transponder (PIT)–Tagged Fish in Small Streams. Transactions of the American Fisheries Society 136:562-566.

Bond M. H. 2006. Importance of estuarine rearing to central California steelhead (*Oncorhynchus mykiss*) growth and marine survival. Master of Arts Thesis, University of California, Santa Cruz.

Bugoni L., T. D. Cormons, A. W. Boyne, and H. Hays. 2005. Feeding grounds, daily foraging activities, and movements of Common Terns in Southern Brazil, determined by radio-telemetry. Waterbirds 28:468-477.

Castro-Santos T., A. Haro, and S. Walk. 1996. A passive integrated transponder (PIT) tag system for monitoring fishways. Fisheries Research: 253-261.

Charnov, E. L. 1976. Optimal foraging: attack strategy of a mantid. American Naturalist. 110:141-151.

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

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

Duhem C., E. Vidal, J. Legrand, and T. Tatoni. 2003. Opportunistic feeding responses of the Yellow-legged Gull *Larus michahellis* to accessibility of refuse dumps. Bird Study 50:61-67.

Furness R.W., K. Ensor, and A. V. Hudson. 1992. The use of fishery waste by gull populations around the British Isles. Ardea 80: 105-113.

Gompper M. E., and A. T. Vanak. 2008. Subsidized predators, landscapes of fear and disarticulated carnivore communities. Animal Conservation. 11:13-14.

Good T. P., R. S. Waples, and P. Adams (Editors). 2005. Updated status of federally listed ESUs of West Coast salmon and steelhead. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-66, 598 p.

Good T.P., M. M. McClure, B. P. Sandford, K. A. Barnas, D. M. Marsh, B. A. Ryan, And E. Casillas. 2007. Quantifying the effect of Caspian tern predation on threatened and endangered salmon in the Columbia River estuary. Endangered Species Research 3:11-21.

Hayes S.A., M. H. Bond, C. V. Hanson, and R. B. MacFarlane. 2004. Interactions between endangered wild and hatchery salmonids: can the pitfalls of artificial propagation be avoided in small coastal streams? Journal of Fish Biology 65 (Supplement A): 101-121.

Hunt, Jr., G.L. 1972. Influence of food distribution and human disturbance on the reproductive success of Herring Gulls. Ecology 53: 1051-1061.

Hunt Jr, G. L., and M. W. Hunt. 1976. Exploitation of fluctuating food resources by Western Gulls. The Auk 93:301-307.

Irons, D. B. 1998. Source Foraging Area Fidelity of Individual Seabirds in Relation to Tidal Cycles and Flock Feeding. Ecology 79:647-655.

King D. T., J. F. Glahn, and K. J. Andrews. 1995. Daily activity budgets and movements of winter roosting Double-crested Cormorants determined by biotelemetry in the Delta Region of Mississippi. Colonial Waterbirds 18 (Special Publication 1):152-157.

Major III, W. W. J. M. Grassley, K. E. Ryding, C. E. Grue, T. N. Pearsons, D. A. Tipton, and A. E. Stephenson 2005. Abundance and consumption of fish by California gulls and Ring-billed gulls at water and fish management structures within the Yakima River, Washington. Waterbirds 28:366-377.

Martindale, S. 1982. Nest defense and central place foraging: a model and an experiment. Behavioral Ecology and Sociobiology 10:85-89.

Massey B. W., K. Keane, and C. Boardman. 1988. Adverse effects of radio transmitters on the behavior of nesting Least Terns. The Condor 90:495-947.

Morris R. D., and J. E. Black. 1980. Radiotelemtry and Herring Gull foraging patterns. Journal of Field Ornithology 51:110-118.

Orians, G.H., and N.E. Pearson. 1978. On the theory of central place foraging. *In* D.Horn, editors. Analysis of ecological systems. Ohio State University Press, Columbus.

Oro D., A. de Leon, E. Minguez, and R.W. Furness. 2005. Estimating predation on breeding European storm-petrals (*Hydrobates pelagicus*) by yellow-legged gulls (*Larus michahellis*). Journal Zoology London 265:421-429.

Parsons K. M., S. B. Piertney, S. J. Middlemas, P. S. Hammond and J. D. Armstrong. 2005 DNA-based identification of salmonid prey species in seal faeces. Journal of Zoology London 266:275-281.

Pierotti R. 1981. Male and female parental roles in the Western Gull under different environmental conditions. The Auk 98: 532-549.

Pierotti, R., and C. A. Annett. 1990. Diet and reproductive output in seabirds: food choices by individual, free-living animals can affect survival of offspring. BioScience. 40:568-574.

Pierotti, R., and C. A. Annett. 1991. Diet choice in the herring gull: constraints imposed by reproductive and ecological factors. Ecology 72:319-328.

Ramos R., F. Ramírez, C. Sanpera, L. Jover, and X. Ruiz. 2009. Diet of Yellow-legged Gull (*Larus michahellis*) chicks along the Spanish Western Medditerranean coast: the relevance of refuse dumps. Journal of Ornithology 150:265-272.

Roby D. D., D. E. Lyons, D. P. Craig, K. Collis, and G. H. Visser. 2003. Quantifying the effect of predators on endangered species using a bioenergetics approach: Caspian terns and juvenile salmonids in the Columbia River estuary. Canadian Journal of Zoology 81:250-265.

Ruggerone G.T. 1986. Consumption of migrating juvenile salmonids by gulls foraging below a Columbia River dam. Transactions of the American Fisheries Society 115:736-742.

Ryan B. A., J. W. Ferguson, R. D. Ledgerwood, and E. P. Nunnallee. 2001. Detection of passive integrated transponder tags from juvenile salmonids on piscivorous bird colonies in the Columbia River basin. North American Journal of Fisheries Management 21:417-421.

Ryan B. A., S. G. Smith, J. A. M. Butzerin, and J. W. Ferguson. 2003. Relative Vulnerability to Avian Predation of Juvenile Salmonids Tagged with Passive Integrated Transponders in the Columbia River Estuary. Transactions of the American Fisheries Society 132:275-288.

Sanz-Aguilar, A., A. Martinez-Abraín, G. Tavecchia, E. Mínguez, and D. Oro. 2009. Evidence-based culling of a facultative predator: Efficacy and efficiency components. Biological Conservation 142:424-431.

Shapovalov L., and A. C. Taft. 1954. The life histories of the steelhead rainbow trout (*Salmo gairdneri gairdnrei*) and silver salmon (*Oncorhynchus kisutch*). California Department of Fish and Game, Fish Bulletin 98:375pp.

Scheel D., and K. R. Hough. 1997. Salmon fry predation near an Alaskan hatchery. Marine Ecology Progress Series 150: 35-48.

Schoener, T.W. 1979. Generality of the size-distance relation in optimal feeding. American Naturalist. 114:902-914.

Sirdevan J. E., and J. S. Quinn. 1997. Foraging patterns of Caspian Terns (*Sterna caspia*) determined using radio-telemetry. Colonial Waterbirds 20(3):429-435.

Spear, L. 1988. Dispersal patterns of Western Gulls from Southeast Farallon Island. The Auk 105: 128-141.

Spear L. B. 1993. Dynamics and effect of western gulls feeding in a colony of guillemots and Brandt's cormorants. Journal of Animal Ecology 62:399-414.

Spence B. C., S. L. Harris, W. E. Jones, M. Goslin, A. Agrawal, E. Mora. 2005. Historical occurance of coho salmon in streams of the central California coast coho salmon evolutionarily significant unit. NOAA-TM-NMFS-SWFSC-383, 89p.

Thayer J. A., and W. J. Sydeman. 2004. Long-term studies of seabirds on Año Nuevo Island and mainland, 2003. In: Final Report to the Monterey Bay National Marine Sanctuaty – Sanctuary Integrated Monitoring Network. Stinson Beach: Point Reyes Bird Observatory. Available: http://www.mbnms-simon.org/docs/project/100251_report.pdf (January 2008).

Underwood, A.J. 1981. Techniques of analysis of variance in experimental marine biology and ecology. *Oceanography and Marine Biology.An Annual Review 19*: 513-605

Wanless S., M. P. Harris, J. A. Morris. 1995. Factors affecting daily activity budgets of South Georgian Shags during chick rearing at Bird Island, South Georgia. The Condor 97:550-558.

Walker R.V., K. W. Myers, N. D. Davis, K. Y. Aydin, K. D. Friedland, H. R. Carlson, G. W. Boehlert, S. Urawa, Y. Ueno, and G. Anma. 2000. Diurnal variation in thermal environment experienced by salmonids in the North Pacific as indicated by data storage tags. Fisheries Oceanography 9:171–186.

Weise M. J., and J. T. Harvey. 2005. Impact of the California sea lion *(Zalophus californianus)* on salmon fisheries in Monterey Bay, California. Fisheries Bulletin 103:685–696.

Wood C. C. 1987a. Predation of juvenile Pacific salmon by the common merganser (*Mergus merganser*) on eastern Vancouver Island. I: Predation during the seaward migration. Canadian Journal of Fisheries and Aquatic Science 44:941-949.

Wood C. C. 1987b. Predation of juvenile Pacific salmon by the common merganser (*Mergus merganser*) on eastern Vancouver Island. II: Predation of stream-resident juvenile salmon by merganser broods. Canadian Journal of Fisheries and Aquatic Science 44:950-959.

Wright B. E., S. D. Riemer, R. F. Brown, A. M. Ougzin, and K. A. Bucklin. 2007. Assessment of harbor seal predation on adult salmonids in a Pacific Northwest estuary. Ecological Applications 17:338-351.

Yorio P., F. Quintana, A. Gatto, Lisnizer, ans N. Suarez. 2004. Foraging patterns of breeding Olrog's Gull at Golfo San Jorge, Argentina. Waterbirds 27:193-199.

APPENDIX

Effects of Radio-tag Attachment

Handling and tagging birds can affect the behavior of a bird, biasing results of telemetry studies (Ackerman et al. 2004). It often is not possible, however, to include appropriate tag controls in avian radio-telemetry studies to assess the effects of tagging on bird behavior. Observations of behavior of tagged and untagged birds have been used in absence of appropriate tag controls (Morris and Black 1980, Massey et al. 1988, Wanless 1995, Sirdevan and Quinn 1997). For example, although Least Terns (*Sterna antillarum browni*) tagged with radio-transmitters abandoned nests and changed foraging behavior relative to untagged birds (Massey et al. 1988), Sirdevan and Quinn (1997) reported no difference in attendance at nests or feeding rates of chicks between tagged and untagged Caspian Terns (*Sterna caspia*). It was not possible to include tagging controls in the present study. Comparison of movements between gulls tagged using different methods (harness or tail-mount) and behavior of birds observed on ANI, therefore, were used to assess effects of tagging.

All Western Gulls tagged using tail-mounted transmitters, which were detected for the duration of the study period, were adults nesting on ANI that bred successfully during 2008 (when tagged) and 2009 (after the tag had dropped off) indicating that there was little effect of tagging on behavior of these birds. Morris and Black (1980) reported that radio-tagged Herring Gulls pulled on tags, antennas, and harnesses used to attach tags to birds, and some birds removed all or part of the antenna. It is likely that some of

the birds that were not detected after tagging or were detected for short period of time were able to remove or damage tail-mounted transmitters used during 2008.

I was unable to test the neoprene harnesses on live birds before deploying them on gulls in the study population. In at least 3 and possibly 4 cases, entanglement in the neoprene harness caused the death of a tagged gull. One other gull was observed entangled in its harness, but the fate of that bird was unknown. I recommend strongly that neoprene harnesses are sized on live Western Gulls before being deployed in the field. I also recommend a thicker neoprene than the 1mm thickness used in this study. A heavier neoprene (3 mm, D. Craig, pers. comm.) may have prevented the ripped harness that eventually resulted in the suspected death of one bird (B19, which bred successfully during 2009). No negative effects of Teflon harnesses were observed, and two gulls shed their Teflon harnesses. Use of Teflon harnesses for tagging Western Gulls therefore, are recommended Despite documented loss of tags by gulls during 2009, enough birds remained tagged throughout the study period to assess movements throughout the breeding season and post-fledging period. Movements of gulls were similar between gulls tagged with Teflon and Neoprene harnesses during 2009 and gulls tagged with tail-mounted transmitters during 2008. Gulls tagged using both harness types and tail-mounted transmitters, which were observed on ANI, exhibited behavior considered normal of breeding Western Gulls. Although it was not possible to fully ascertain the effects of tagging on gull behavior, movements and breeding behavior of tagged gulls indicated that unless a harness caused death, effects of tagging on gull behavior were minimal and unlikely to affect the conclusions of this study.

CONCLUSIONS

This study provided the first estimates of predation of salmonids from small, coastal watersheds in central California. Recoveries of PIT Tags from Año Nuevo Island (ANI) combined with Mark-Recapture modeling indicated that predation rates may exceed 3% of all tags deployed in some coastal watersheds. Although some predation of adult salmonids by California sea lions using ANI occurred, the majority of predation was by Western Gulls that breed on ANI. Predation occurred primarily during downstream migration immediately before or after ocean entry. Although overlap between Western Gulls and juvenile salmonids was rare in time and space, predation was 100% when overlap occurred.

Western Gulls breeding on ANI act as subsidized predators, and recent increases in the ANI breeding population was likely due to anthropogenic food subsidies. Although the per capita predation rate by Western Gulls breeding on ANI is likely low, population level predation rates may be great enough to limit recovery of central California coho and steelhead, when combined with other pressures faced by these depleted populations. Even if per capita predation rates remain low, predation pressure will increase as gull populations increase and salmonid populations continue to decrease.

Mortality of juvenile salmonids during freshwater rearing has a disproportionate effect on numbers of returning adult fish, compared with mortality during other life stages. Management actions that reduce predation of juvenile salmonids by Western Gulls at ocean entry, therefore, may enhance recovery of central California salmonids.

LITERATURE CITED

Anderson SK, Roby DD, Lyons DE, Collis K (2007) Relationship of Caspian tern foraging ecology to nesting success in the Columbia River estuary, Oregon, USA. Est Coast Shelf Sci 73:447-456

Castro-Santos T, Haro A, Walk S (1996) A passive integrated transponder (PIT) tag system for monitoring fishways. Fisheries Research: 253-261

Collis K, Roby DD, Craig DP, Ryan BR, Ledgerwood RD (2001) Colonial waterbird predation on juvenile salmonids tagged with passive integrated transponders in the Columbia River estuary: vulnerability of different salmonid species, stocks, and rearing types. Trans Am Fish Soc 130: 385-396

Good TP, McClure MM, Sandford BP, Barnas KA, Marsh DM, Ryan BA, Casillas E (2007) Quantifying the effect of Caspian tern predation on threatened and endangered salmon in the Columbia River estuary. Endang Species Res 3:11-21

Major III, WW. Grassley JM, Ryding KE, Grue CE, Pearsons TN, Tipton DA, Stephenson AE (2005) Abundance and consumption of fish by California gulls and Ring-billed gulls at water and fish management structures within the Yakima river, Washington. Waterbirds 28(3):366-377

Parsons KM, Piertney SB, Middlemas SJ, Hammond PS, Armstrong JD (2005) DNA-based identification of salmonid prey species in seal faeces. J Zool Lond 266:275-281

Roby DD, Lyons DE, Craig DP, Collis K, Visser GH (2003) Quantifying the effect of predators on endangered species using a bioenergetics approach: Caspian terns and juvenile salmonids in the Columbia River estuary. Can J Zool 81: 250-265

Spence BC, Harris SL, Jones WE, Goslin M, Agrawal A, Mora E (2005) Historical occurance of coho salmon in streams of the central California coast coho salmon evolutionarily significant unit. NOAA-TM-NMFS-SWFSC-383, 89p.

Weise MJ, Harvey JT (2005) Impact of the California sea lion *(Zalophus californianus)* on salmon fisheries in Monterey Bay, California. Fish Bull 103:685–696

Wright BE, Riemer SD, Brown RF, Ougzin AM, Bucklin KA (2007) Assessment of harbor seal predation on adult salmonids in a Pacific Northwest estuary. Ecological Applications 17(2):338-351