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# Assessing the Relationship between Gulls Larus spp. and Pacific Salmon in Central California Using Radiotelemetry

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ARTICLE

# Assessing the Relationship between Gulls *Larus* spp. and Pacific Salmon in Central California Using Radiotelemetry

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***Abstract***
**Predation by marine birds has resulted in substantial losses to runs of Pacific salmon *Oncorhynchus* spp., in some cases necessitating management action. Recovery of PIT tags on a seabird breeding colony (Año Nuevo Island) indicated that western gulls *Larus occidentalis* prey upon federally listed Coho Salmon *Oncorhynchus kisutch* and steelhead *O. mykiss* in central California. Whereas salmonid populations in central California have decreased in recent decades, the western gull population on Año Nuevo Island has increased. We observed gulls *Larus* spp. within estuaries to document predation and used radiotelemetry to examine gull movement in relation to the availability of salmonids. During 2008 and 2009, observed predation events of out-migrating salmonids by gulls**

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**were rare; 21 events occurred during 338 h of observations at two estuaries. During the prehatch and chick-rearing phases of breeding, which coincided with migration of salmonids from fresh to salt water, 74% of the detections of radio-tagged western gulls occurred within 25 km of Año Nuevo Island, suggesting that the relative susceptibility of predation by western gulls using Año Nuevo Island decreased with distance from the island. Western gull presence at creek mouths was greatest during daylight hours (91% of detections), while juvenile salmonids were present predominantly at night (65% of detections). The greatest overlap between western gulls and salmonids occurred at dusk, and predation of out-migrating salmonids was likely opportunistic. Deterring gulls from creek mouths when overlap between predator and prey might otherwise occur may buffer out-migrating salmonids from predation. Our results will inform management strategies to most effectively reduce the impacts of gull predation on central California salmonids.**



Predation by piscivorous birds has been well documented as a source of mortality for Pacific salmon *Oncorhynchus* spp. in Washington, Oregon, and California (Collis et al. 2001; Adrean et al. 2012; Evans et al. 2012), where many populations are listed as threatened or endangered under the U.S. Endangered Species Act (Gustafson et al. 2007). Recently, predation by western gulls *Larus occidentalis* has been identified as a source of mortality that is potentially limiting the recovery of imperiled salmonid species in central California, which already face numerous other challenges to recovery (Miller 2010; Frechette et al. 2012; Osterback et al. 2013). Coho Salmon *O. kisutch* and steelhead *O. mykiss* are among the imperiled species, and the central California coast steelhead distinct population segment is currently listed as threatened under the U.S. Endangered Species Act, and the central California coast Coho Salmon evolutionary significant unit is listed as endangered (Good et al. 2005).

To enhance understanding of the population biology of Coho Salmon and steelhead, an intensive program to tag juvenile salmonids with Passive Integrated Transponder (PIT) tags was initiated in 2002. Tags originally deployed in juvenile salmonids in Santa Cruz and San Mateo counties, California, subsequently were recovered in a western gull breeding colony located on Año Nuevo Island (Frechette et al. 2012). Based on estimates of tag deposition on Año Nuevo Island, western gulls ate a minimum of 1% to 4% of the tagged juvenile salmonids originating in watersheds closest to the island (Frechette et al. 2012). More recently, estimates accounting for the probability of a western gull transporting an ingested tag to Año Nuevo Island indicated that predation rates of tagged steelhead are greater than estimates from tag deposition alone (Osterback et al. 2013). The median probability of predation by western gulls using Año Nuevo Island was $\geq$ 30% but could be as great as 80% for some watersheds and years (Osterback et al. 2013). These estimates are of particular concern, as the western gull population on Año Nuevo Island increased substantially during the last 30 years, from 120 nests in 1976 to 904 nests in 2014 (R. Carle, J. Beck, D. Calleri, and M. Hester, 2014 unpublished report to the California Department of Parks and Recreation, on seabird conservation and habitat restoration).

The ecology of a predator and its prey affects the susceptibility of the prey to predation. The timing of breeding, body size, energetic requirements, foraging strategy, foraging location, and age all may affect predation rates on juvenile salmonids (Wood 1987a, 1987b; Collis et al. 2001, 2002; Major et al. 2005; Anderson et al. 2007). Like many seabirds, western gulls are central place foragers during the breeding season and are limited in the distance traveled and the duration of foraging trips by the need to return to their nests (Sirdevan and Quinn 1997). Further, as generalist predators, western gulls forage opportunistically and exploit prey when it is available (Major et al. 2005). The susceptibility of juvenile salmonids to predation by western gulls may be affected by differences in foraging habits between breeding and nonbreeding birds and between breeding and nonbreeding seasons, as well as the tendency to exploit salmonids when available. Additionally, the timing of smolt out-migration, behavior of smolts, and availability of alternative prey may change the susceptibility of juvenile salmonids to predation (Wood 1987a, 1987b; Scheel and Hough 1997; Collis et al. 2001, 2002; Roby et al. 2003; Anderson et al. 2007). Understanding the foraging ecology and behavior of western gulls breeding on Año Nuevo Island, especially in relation to the availability of juvenile salmonids as prey, is essential for evaluating the effects of this predator on the recovery of salmonids in central California.

Although the role of generalist gulls *Larus* spp. in limiting populations of depleted fish has received increasing attention, little information is available to managers that would aid in resolving these impacts (Ruggerone 1986; Major et al. 2005; Frechette et al. 2012; Osterback et al. 2013). The objective of our study was twofold. First, we identified the spatial and temporal overlap between western gulls and juvenile salmonids originating in Santa Cruz and San Mateo County watersheds. We expected that the foraging range of western gulls breeding on Año Nuevo Island would increase as chicks became larger and more independent, thereby affecting the seasonal susceptibility of juvenile salmonids to western gull predation at streams of varying distance from Año Nuevo Island. Further, we expected that if western gulls targeted juvenile salmonids as a source of prey, we would observe spatial and temporal overlap between western gulls and salmonids during smolt out-migration, when smolts were most susceptible to predation by gulls. Second, we assessed the potential for the disturbance of western gulls at creek mouths to be used as a management strategy. We tested the hypothesis that the presence of human disturbance reduces the number of western gulls at salmonid creeks, thereby reducing predation potential.

## METHODS

*Study site*.—We studied two watersheds in central California, Waddell Creek (37°5′N, 122°16′W) and Scott Creek (37°2′N, 122°13′W), because of their proximity to Año Nuevo Island and because of concurrent monitoring programs of salmonid life history and population dynamics. Waddell Creek is approximately 5.5 km and Scott Creek approximately 12 km from Año Nuevo Island. Each watershed terminates in a small estuary that becomes a freshwater lagoon during the summer when deposition of beach sand closes off stream flow to the ocean, a feature typical of watersheds in central California (Shapovalov and Taft 1954; Hayes et al. 2004). High flows associated with winter rains break open the sandbars, allowing adult salmonids access to upstream spawning habitat and out-migrating juvenile salmonids (termed smolts) access to the ocean (Shapovalov and Taft 1954). The outmigration of Coho Salmon smolts occurs primarily in April and May, whereas the out-migration of steelhead smolts occurs from January through June (Hayes et al. 2008).

*Predation observations and flock composition*.—We conducted visual observations at Scott and Waddell creeks during daylight hours to count gulls (all species) and document predation attempts in the lower estuary and creek mouth. We conducted observations weekly from March to July 2008 and January to April 2009 to coincide with smolt out-migration. We used a protocol modified from Major et al. (2005). We observed gulls in hour-long cycles beginning at sunrise and concluded observations when no gulls were present for 1 h. Observers counted gulls at the start of each hour, then watched the creek mouth and lower estuary for 20 min and recorded all predation attempts on juvenile salmonids. Following the first 20-min observation period, a second count was made, followed by a second 20-min observation period. At the end of the second observation period, a third count was conducted. Observers were given a break from the end of the third count to the start of the next hour. We conducted observations in the open (no blind) less than 100 m from each creek. We observed predation with the unaided eye, confirming with 8 × 42 binoculars or a spotting scope if necessary, and made all counts using 8 × 42 binoculars. Both Coho Salmon and steelhead were present in Scott and Waddell creeks, and we could differentiate prey to genus only. No observations occurred on days when gulls were captured, and observations were suspended for a minimum of 5 d after capture attempts.

We characterized the size and composition of gull flocks at Scott and Waddell creeks using counts conducted during predation observations. Because gull numbers fluctuated greatly throughout the day, we randomly selected one count from each day when predation observations were conducted to estimate mean flock size. Observers were not always capable of identifying the age-class and species of gull due in part to the large numbers present and flushing behavior. We classified flock composition from all counts when species ID and age were recorded.

During the initial observations at Scott and Waddell creeks, we observed that the presence of humans on the beaches seemed to decrease the presence of gulls in and around creek mouths, which could buffer salmonids from predation. Thus, we conducted continuous predation observations from sunrise to sunset between March 28 and April 2, 2009. During these continuous observations, we counted gulls every half hour and recorded the presence and type of human disturbance. All cases of observed disturbance involved people walking in or within 20 m of the creek mouth, including general beachgoers, surfers accessing the ocean, and kite surfers setting up their kites either in or next to the creek mouth before accessing the ocean. We used a two-sample *t*-test (R Development Core Team 2012) to test whether the mean number of gulls differed in the presence of human disturbance.

*Movements of western gulls*.—We used radiotelemetry to examine the movements of adult western gulls in relation to the stages of the gull breeding cycle. We deployed VHF radio transmitters on western gulls captured on the beach at Scott Creek (2 attempts; February 24 and May 11, 2009) and Waddell Creek (3 attempts; February 25 and 26 and May 12, 2009). Although we planned to deploy tags only on adult western gulls, we tagged fourth-year birds ($N = 5$) and juveniles (less than 4 years old, $N = 2$) when we did not capture enough adults to deploy all tags. Logistic and permitting restrictions prevented capture at Año Nuevo Island.

To capture western gulls, we used two cannon nets (each 10 m wide × 20 m long) with weighted projectiles, one propelled using black powder and the other compressed air. We set the nets on the beaches before sunrise (between 0400 and 0700 hours local time) and attracted western gulls to the nets using food items. Upon capture, we removed the birds from the nets, placed them in cardboard pet carriers, and transported them about 30 km to the National Oceanic and Atmospheric Administration (NOAA) Southwest Fisheries Science Center in Santa Cruz, California. Transport of the birds was necessary because adverse weather conditions prevented tagging them on the beaches and was approved by institutional animal care committees. We banded all western gulls captured ($N = 65$) with a U.S. Fish and Wildlife Service steel band and colored plastic band with alphanumeric combinations. We tagged a subset of 40 western gulls (Supplementary Table S.1 available in the online version of this article) with backpack-mounted VHF transmitters (49 mm long by 16 mm in diameter; 19 g mass; battery capacity 654 d; Advanced Telemetry Systems, Isanti, Minnesota), which we attached to the birds using harnesses constructed either of Teflon ribbon (Belant et al. 1998) or 1-mm rubber neoprene (D. Craig, Willamette University, personal communication). We attempted to deploy 10 of each tag type at each watershed. The average mass of the tag and harness package (both types) was 2.57% of the average mass of the western gulls handled ($\bar{x} = 998.7$ g; SD = 12.4). Western gulls were released at their capture beach within 12 h of capture and observed until they flew away to ensure no injuries occurred during handling.

We subsequently located radio-tagged western gulls from vantage points along an approximately 50-km section of coastline that encompassed all creeks from which PIT tags on Año Nuevo Island originated (described by Frechette et al. 2012) and potential alternative foraging sites, including intertidal areas and a landfill (Figure 1). Sites were approximately 5 km apart to ensure complete coverage of the coastline, except where agricultural fields prevented coastal access (between Davenport and Natural Bridges). We located tagged western gulls from coastal roads using a portable radio receiver (R4000; Advanced Telemetry Systems) and handheld three-element Yagi antenna. We conducted 24 radio-tracking surveys by car once every 7–14 d between March 10 and October 30, 2009, to span the western gull breeding season and part of the smolt out-migration period. We randomized the date, start time, and direction of travel (north to south or south to north) to account for daily variation in western gull behavior. We determined the presence or absence of western gulls from the signal strength and then confirmed locations using triangulation or visual observation. We conducted two aerial surveys from Point Sur in the south to San Francisco Bay in the north and out to the Farallon Islands (total transect distance ~250 km). Aerial surveys were flown in June 2009 (during chick rearing) and September 2009 (after chicks fledged) to locate tagged birds that had dispersed out of the primary study area.

We installed automatic data collection systems (hereafter referred to as ADCSs), consisting of a four-element Yagi antenna, radio receiver (R4000; Advanced Telemetry Systems), and data logger (ADCSII; Advanced Telemetry Systems) at Scott and Waddell creeks to continually log the presence or absence of radio-tagged western gulls at the mouth of each creek. We programmed the ADCSs to monitor each radio frequency for a period of 10 s, every 7 min, from late February 2009 until mid-October 2009. A radio-tagged western gull was considered present if it was detected at least once by the ADCS during consecutive scans (detections of birds on capture dates were excluded from analysis). Data collected by the ADCSs indicated that the presence of radio-tagged western gulls at Scott and Waddell creeks was independent of the site of capture ($\chi^2_{(3,\, N\,=\,34)}$, $P > 0.05$), so we combined the detections of western gulls captured and tagged at Scott and Waddell creeks for subsequent analyses of active radio-tracking and ADCS data.

We defined the stages of the breeding season based on western gulls that were opportunistically observed on Año Nuevo Island during 2009 (P. Morris, University of California Santa Cruz, personal communication). The prospecting phase of the breeding cycle was from March 1 (the start of the study) until the day before the first egg was found on Año Nuevo Island (April 30). Incubation was from the date the first egg was found (May 1) until the day before the first chick was seen (June 3), and chick rearing was from the date the first chick was seen (June 4) until the date at which approximately half of the chicks were no longer fed by parents (August 15). We defined postfledging as the period between August 16 and October 31. Because the number of western gulls with radio

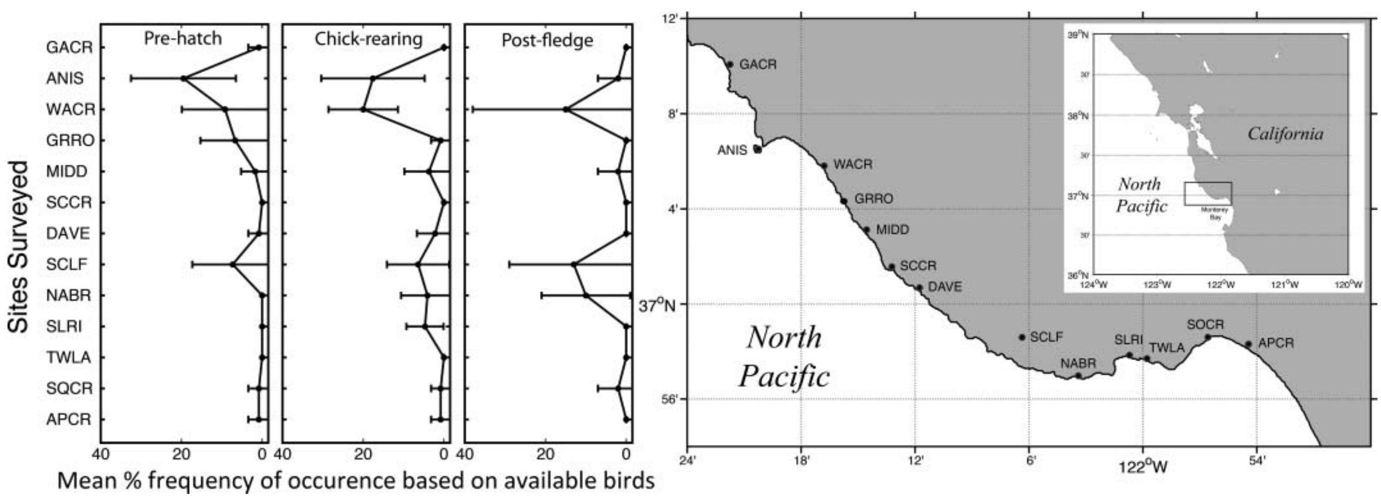


FIGURE 1. Mean ± SE frequency of occurrence (left panel) of radio-tagged western gulls detected with increasing distance (km) from Año Nuevo Island during 2009. Data are presented as the mean percent frequency of occurrence (percentage of the total number of western gulls available for tracking on a given date) during prehatch, chick-rearing, and postfledging phases of the breeding cycle. For the map of survey site locations (right panel), the land is shown in gray and the ocean in white. The location abbreviations and their distance from Año Nuevo Island (ANIS) follow, grouped by type of foraging site. Watersheds where salmonids occur: Gazos Creek (GACR; 6.6 km), Waddell Creek (WACR; 5.5 km), Scott Creek (SCCR; 12.0 km), San Lorenzo River (SLRI; 33 km), Soquel Creek (SOCR; 38 km), and Aptos Creek (APCR; 41 km). Intertidal and alternative foraging areas: Greyhound Rock (GRRO; 7 km); Middle (MIDD; 10.5 km), Davenport (DAVE; 16.0 km), Natural Bridges (NABR; 30.4 km), Twin Lakes (TWLA; 34.3 km), and Santa Cruz landfill (SCLF; 25.4 km).

tags varied throughout the study (due to staggered tagging effort, tag loss, and movement of birds out of the study area), we standardized radio-tracking data. We divided the number of birds detected at each tracking location on a given day by the number of birds available for tracking and expressed the result as a percentage (hereafter referred to as "frequency of occurrence"). We graphically examined the frequency of occurrence (from car-based and aerial surveys) in relation to the stages of the gull breeding cycle to examine the foraging range of western gulls breeding on Año Nuevo Island as chicks became larger and more independent. We tested whether the presence of radio-tagged western gulls at Scott and Waddell creeks (detected by ADCSs) varied by site and phase of the breeding cycle using a two-way analysis of variance (ANOVA) (Model I; SPSS 2007). As described for the active tracking data, we accounted for tag loss by dividing the number of birds detected by the ADCSs on a given day by the number of birds available for tracking.

*Overlap with salmonids*.—We assessed the overlap between western gulls and salmonids during smolt out-migration at Scott Creek, where the ADCS enabled the detection of tagged western gulls and an instream PIT tag antenna, hereafter referred to as the beach antenna, enabled the detection of PIT-tagged juvenile salmonids (Bond et al. 2007). The beach antenna was installed on March 26, 2009, approximately 100 m upstream from where Scott Creek enters the ocean and was operated until lagoon closure on July 21, 2009. High winter creek flows prevented the installation of the beach antenna before March 26. We defined peak smolt out-migration by the number of PIT-tagged out-migrants detected by the beach antenna on a daily basis. We classified juvenile salmonids as out-migrants if they were detected by the beach antenna before lagoon closure and were not detected after lagoon closure by this or other PIT tag antennas upstream of the lagoon. We present only minimum numbers of out-migrants because PIT tag antenna efficiency was variable.

Juvenile steelhead and Coho Salmon have been PIT-tagged at several locations throughout the Scott Creek watershed since 2002 as part of on-going research conducted by the NOAA Southwest Fisheries Science Center (see Hayes et al. 2004 for detailed fish handling techniques and Hayes et al. 2011 [their Figure 1] for tagging locations). Coho Salmon were extremely rare during the study period (only seven wild Coho Salmon were PIT-tagged during 2009), so the majority of PIT-tagged Coho Salmon smolts out-migrating in 2009 originated in a small California Department of Fish and Wildlife cooperative conservation hatchery operated in the Scott Creek watershed. The hatchery released 980 PIT-tagged and 860 untagged Coho Salmon smolts during March 2009. Based on steelhead life history in Scott Creek (Hayes et al. 2011), PIT-tagged steelhead smolts that out-migrated during 2009 were individuals that were (1) captured by seining in the estuary and by electrofishing in the upper watershed during 2008 (678 tagged individuals), (2) captured in smolt traps on the lower main stem of Scott Creek during 2009 (1,430 tagged individuals), or (3) steelhead tagged and released from the conservation hatchery (2,945 of the 4,738 hatchery steelhead released).

We compared detections of tagged western gulls by the ADCS at Scott Creek with detections of PIT-tagged salmonid out-migrants by the beach antenna to identify temporal overlap between the presence of western gulls at the creek mouth and the movement of PIT-tagged salmonids out of the creek. We assumed that untagged birds were present at Scott Creek during the same hours that tagged birds were detected by the ADCS and that untagged salmonid smolts migrated to sea at the same time as PIT-tagged smolts. The patterns of smolt out-migration were similar between Scott and Waddell creeks (S. A. Hayes, unpublished), so we used a two-sample Kolmogorov–Smirnov test to compare daily detections of western gulls to determine whether there was a difference between Scott and Waddell creeks in the hours that western gulls were present at each creek mouth during each phase of the breeding cycle (SYSTAT 2000).

## RESULTS

### Predation Observations and Flock Composition

During 2008, we observed zero predation events at Waddell Creek (45 h of observation; $n = 11$ occasions, March 13 to July 10). We observed 20 predation events at Scott Creek (62.6 h of observation; $n = 16$ occasions, March 8 to July 9). These 20 juvenile salmonids were swimming through the last 15 m of Scott Creek before entering the ocean when they were captured and eaten by western gulls (50% by juveniles and 50% by adult gulls) during a 3-hr period on April 11, 2008. During 2009, we observed one predation event at Scott Creek in 132.0 h of observations ($n = 18$ occasions, January 9 to April 2). We observed no predation events at Waddell Creek during 2009 during 98.4 h of observations ($n = 14$ occasions, January 21 to April 2).

At Scott Creek the mean flock size was 135 gulls per day (SD = 151; range = 0–699 gulls). At Waddell Creek, the mean flock size was 76 gulls (SD = 79; range = 0–204 gulls). The flat nature of the beach at Waddell Creek made it difficult to reliably identify gulls to species; therefore, we only characterized gull flocks at Waddell Creek by age-class. Mean flock composition at Waddell Creek was 69% adults (SD = 30) and 31% juveniles (SD = 70), which was similar to the flock composition at Scott Creek (Table 1).

During sunrise-to-sunset observations, we recorded a total of 162 counts of gulls at each creek. At Scott Creek, disturbance (all forms) was present during every hour between sunrise and sunset and kite surfers were present between 1000 hours (all times are Pacific Standard Time) and sunset, which occurred at approximately 1930 hours during observations. At Waddell Creek, disturbance (all forms) occurred throughout the daylight hours, while we observed kite surfers

TABLE 1. Mean percent composition of gull flocks at Scott Creek, California, by species and age-class.

| Species and age-class | Mean (%) | SD |
|---|---|---|
| **Species** | | |
| Western gull | 56 | 33 |
| California gull *Larus californicus* | 14 | 23 |
| Other species | 3 | 14 |
| Unidentified gulls | 27 | 30 |
| **Age-class** | | |
| Adults | 61 | 25 |
| Juveniles | 34 | 23 |
| Not assigned | 5 | 19 |



between 1100 and 1800 hours. Human disturbance (all forms) was present during 52 of 162 counts at Scott Creek. Kite surfers were present during 39 of the 52 counts when disturbance was observed. At Waddell Creek, human disturbance (all forms) was present during 30 of 162 counts and kite surfers were present during 16 of the 30 counts when disturbance was observed. Because we recorded fewer counts with disturbance than without disturbance, we randomly sampled counts without disturbance to generate an equal number of counts with and without disturbance to test for a difference in the number of gulls at creek mouths with and without disturbance. Assumptions of normality and equal variance were met for all comparisons and we used alpha of 0.1 for interpreting *t*-tests.

The mean number of gulls on the beach at Scott Creek (Figure 2, top panels) was slightly less in the presence of human disturbance ($\bar{x} = 9.96$, SE = 3.4; $n = 52$) than in the absence of disturbance ($\bar{x} = 15.88$, SE = 4.0; $t = 1.6184$, df = 98.892, $P = 0.109$). The mean number of gulls in the presence of kite surfers ($\bar{x} = 2.36$, SE = 1.4; $n = 39$) was significantly less than the mean number of gulls in the absence of kite surfers ($\bar{x} = 17.49$, SE = 5.38; $t = 2.725$, df = 42.825, $P = 0.009$). The mean number of gulls on the beach at Waddell Creek (Figure 2, bottom panels) was less in the presence of human disturbance ($\bar{x} = 58.4$, SE = 12.3; $n = 30$) than in the absence of disturbance ($\bar{x} = 85.6$, SE = 15.3), however, the difference was not deemed statistically significant ($t = 0.3824$, df = 55.429, $P = 0.172$). The mean number of gulls in the presence of kite surfers at Waddell Creek ($\bar{x} = 34.00$, SE = 10.9; $n = 16$) was less than the mean number of gulls in the absence of kite surfers, ($\bar{x} = 59.81$, SE = 15.9), but again the difference was not statistically significant ($t = 1.3642$, df = 26.951, $P = 0.184$).

## Movements of Adult Western Gulls

We detected 34 of 40 tagged western gulls after release. The mean duration between release and last detection was 152 d (range = 4–351 d). Consistent detections of many individuals at the same location indicated that tagged western gulls exhibited site fidelity to foraging sites and day roosts (Table S.1). Of the 34 western gulls detected after release, we detected 27 of them from established survey points, whereas the remaining seven western gulls were detected either by ADCSs at Scott or Waddell creeks or during aerial surveys. Too few surveys were conducted during the prospecting and incubation phases of the breeding cycle for comparison with the chick-rearing and postfledging phases, so we combined data from the prospecting and incubation periods into a “prehatch period” (March 1 to June 3; $n = 8$ surveys: 7 daytime, 1 nighttime). We conducted nine surveys (seven daytime, two nighttime) during chick rearing and six surveys (five daytime, one nighttime) during postfledging. We considered only western gulls detected during active tracking when examining gull movements ($n = 27$).

We identified 14 radio-tagged adult western gulls using Año Nuevo Island during active radio-tracking. Of these, eight were visually observed on the island and two were observed rearing chicks. For western gulls that used Año Nuevo Island ($n = 14$; Table S.1), we observed a decreasing trend in the mean percent frequency of occurrence of the radio-tagged western gulls with increasing distance from Año Nuevo Island during the prehatch period (Figure 1), with the exception of the Santa Cruz landfill. We observed a similar trend during chick rearing; however, we also observed an increased number of Año Nuevo Island western gulls at Natural Bridges and the San Lorenzo River. We did not conduct tracking at Natural Bridges during the prehatch period, so no comparison can be made between these two periods at this site. The greatest change we observed was the near absence of detections at Año Nuevo Island during postfledging and a concurrent increase in detections at the Santa Cruz landfill, Natural Bridges, and the San Lorenzo River.

For birds that were detected at Año Nuevo Island, their use of the island was greatest during the prehatch and chick-rearing periods and decreased dramatically during postfledging (Figure 3A). Creeks (predominantly Waddell Creek) were the second most-used habitat during prehatch and chick rearing and the most-used habitat postfledging. Landfill and intertidal or ocean habitat use also increased during the postfledging period compared with the previous two phases of the breeding cycle.

We identified 13 radio-tagged western gulls during active radio-tracking that did not use Año Nuevo Island during 2009 (10 adults, 3 fourth-year gulls). We refer to these birds as non–Año Nuevo Island gulls because we were unable to determine whether these birds bred elsewhere. Tagged non–Año Nuevo Island gulls were detected most frequently at the landfill during the prehatch period (Figure 3B). Creeks were the second most-used habitat. The use of creeks, intertidal or ocean habitat, and the wharf in Santa Cruz increased during chick rearing, whereas the use of the landfill decreased substantially. By the postfledging period, birds only were being located using intertidal or ocean habitat and the Santa Cruz wharf. We consistently located one adult western gull at the Santa Cruz

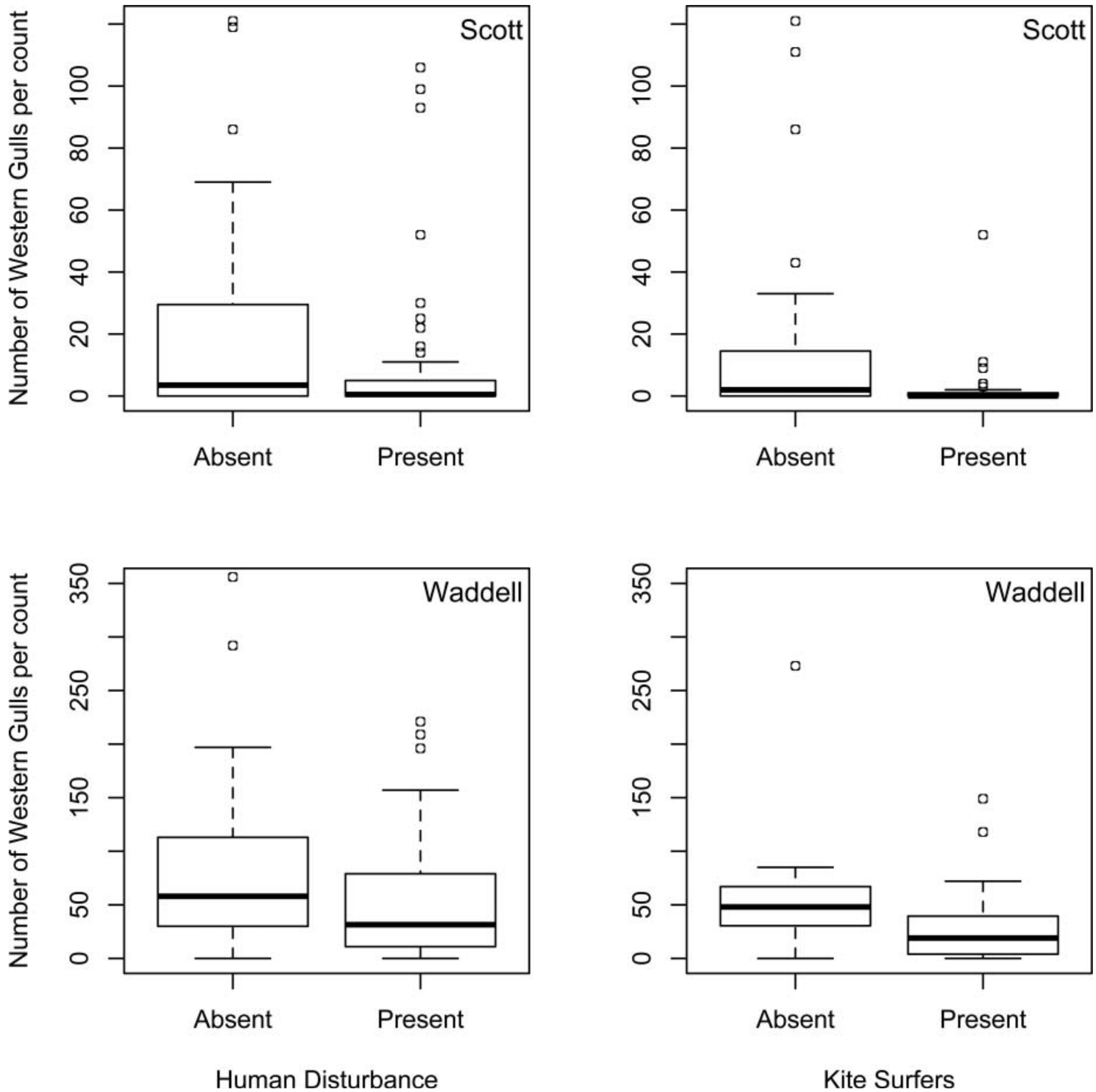


FIGURE 2. Western gulls present at Scott (top panels) and Waddell (bottom panels) creeks in the presence and absence of all forms of human disturbance (left panels) and the presence and absence of kite surfers (right panels). Whiskers represent 95% confidence intervals, box dimensions represent first and third quartiles, solid black lines represent medians, and open circles represent outliers. Note the different *y*-axes for Scott and Waddell creeks.

wharf, just north of the San Lorenzo River, during the chick-rearing and postfledging periods, leading to the apparently high use of the wharf.

We observed fairly high use of the Santa Cruz landfill by tagged western gulls. Although the mean number of western gulls detected at the landfill during any phase of the breeding cycle was fewer than 15% of the functioning radio tags deployed at a given time (Figure 3), 16 radio-tagged western gulls were detected at some point at the landfill. Of the western gulls detected at Año Nuevo Island during 2009, 64% used the landfill (9 out of 14 birds). Additionally, one western gull, which was observed on Año Nuevo Island visually and during radio-tracking surveys, was detected at a landfill located in Watsonville, California (52.1 km from Año Nuevo Island), during the June 2009 aerial survey.

We detected 29 radio-tagged western gulls by the ADCS at Scott Creek and 28 by the ADCS at Waddell Creek. Sufficient data were collected by the ADCSs to compare detections of western gulls at the two creeks during all four phases of the breeding cycle (prospecting, incubation, chick rearing, and postfledging). Using a two-way Model I ANOVA, we tested whether the presence of tagged western gulls at Scott and Waddell creeks varied by site and phase of the breeding cycle. There was a significant site-by-season interaction (Table 2),

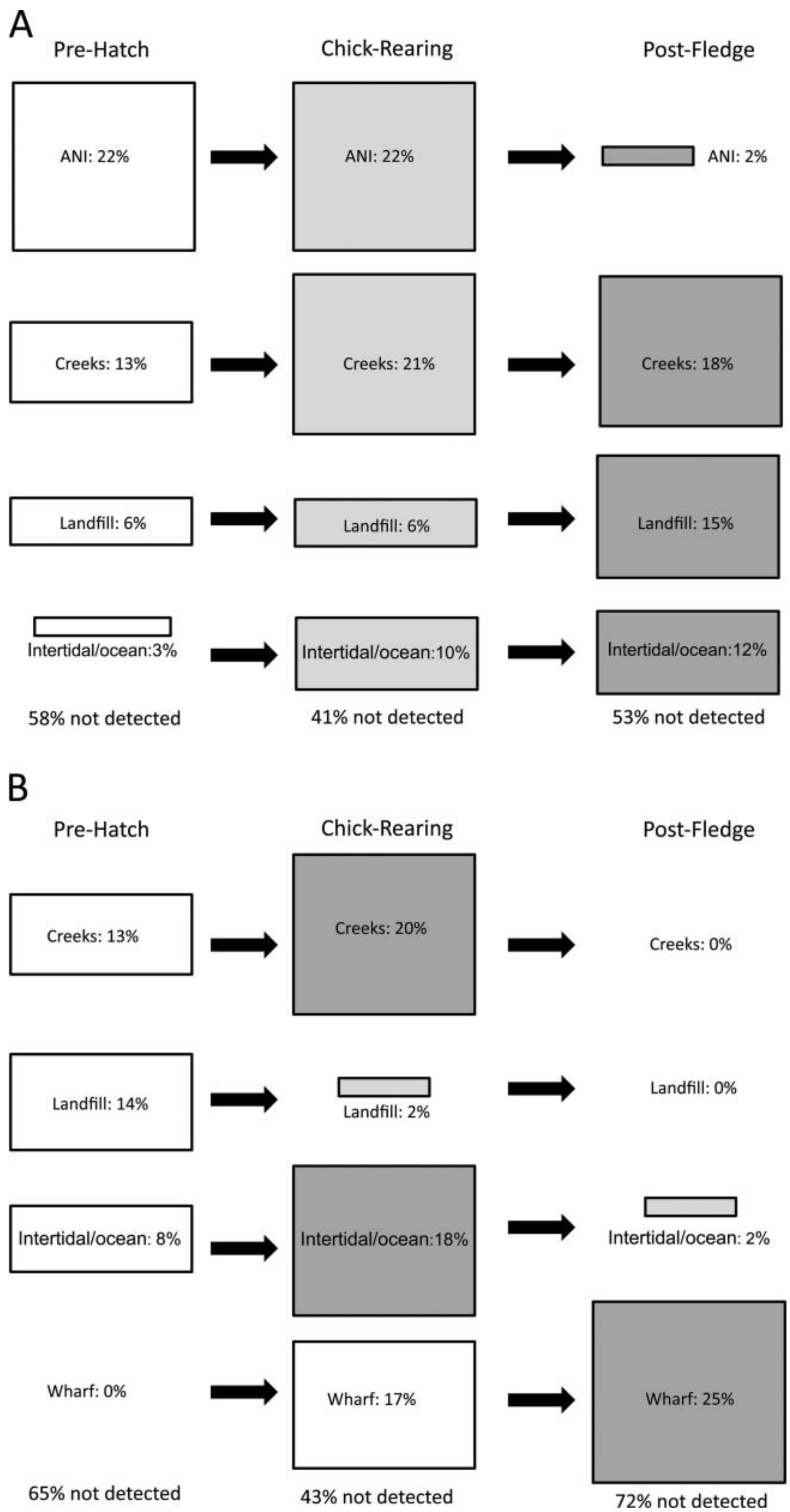


FIGURE 3. Change in habitat use throughout the breeding cycle (prehatch, chick rearing, and postfledging) by radio-tagged western gulls that either **(A)** used Año Nuevo Island (ANI) or **(B)** did not use Año Nuevo Island during 2009. Percentages reflect the mean frequency of occurrence for each habitat type, relative to the number of western gulls available for tracking.

TABLE 2. Two-factor ANOVA comparing the attendance of western gulls at Scott and Waddell creeks during each phase of the breeding cycle during 2009.

| Breeding phase | Source | Sum of squares | Degrees of freedom | Mean square | *F*-ratio | *P*-value |
|---|---|---|---|---|---|---|
| Prospecting, incubation, chick rearing, and postfledging | Site | 0.215 | 1 | 0.215 | 27.061 | <0.001 |
| | Season | 0.069 | 3 | 0.023 | 2.900 | 0.036 |
| | Site × season | 0.174 | 3 | 0.580 | 7.323 | <0.001 |
| | Error | 1.554 | 196 | 0.008 | | |
| Prospecting, incubation, and chick rearing | 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 | | |



indicating that the use of the two sites (Scott and Waddell creeks) by radio-tagged western gulls differed throughout the breeding season (Figure 4). When the postfledging period was excluded from analysis, the seasonal effect was not significant, but the mean number of birds detected per day (relative to the number of birds tagged) was greater at Waddell Creek than at Scott Creek.

## Overlap with Salmonids

The beach PIT tag antenna at Scott Creek detected 1,254 PIT-tagged juvenile salmonids, of which 1,236 individuals had unambiguous capture histories recorded. We detected 1 Coho Salmon of natural origin and 88 Coho Salmon of hatchery origin passing through the antenna. We detected 164 steelhead of natural origin and 983 of hatchery origin. Detections of juvenile salmonids by the instream PIT tag antenna at Scott Creek occurred consistently until the end of May, and 98% of detections occurred by June 18 (Figure 5). However, while the beach antenna was operational, 75% of all detections occurred between March 26 and April 21, 2009, which we defined as peak smolt out-migration. On March 30, the beach antenna detected 376 uniquely tagged salmonids, representing 26% of the total detections. This coincided with a release of 995 steelhead from the hatchery. Removal of the tags from March 30 did not affect the distribution of tags detected during the 24-h period (two-sample Kolmogorov–Smirnov [KS] test: $P = 0.980$); therefore, we included detections from March 30 in subsequent analyses.

During peak smolt out-migration (March 26 to April 21), most detections of juvenile salmonids (65%) occurred during

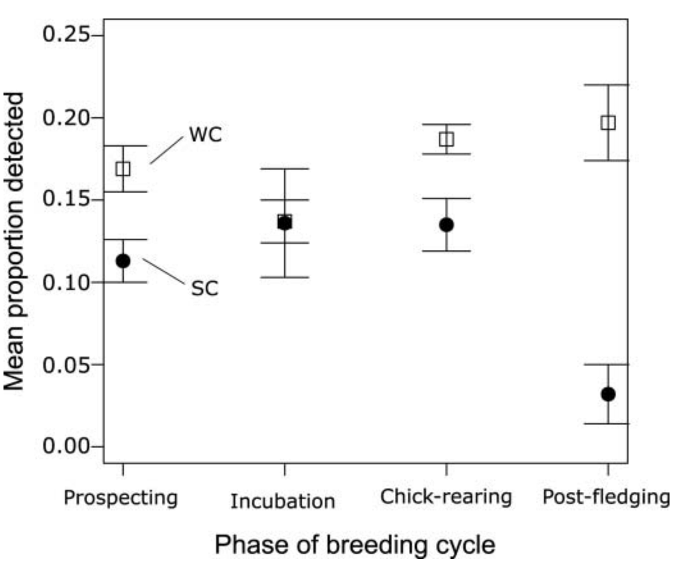


FIGURE 4. Mean proportion (error bars indicate SE) of radio-tagged western gulls attending Scott Creek (SC; closed circles) and Waddell Creek (WC; open squares) throughout the breeding cycle (prospecting, incubation, chick rearing, and postfledging) based on continuously recorded detections. Data were standardized by dividing the number of western gulls detected per day by the number of tagged western gulls available for tracking on that date.

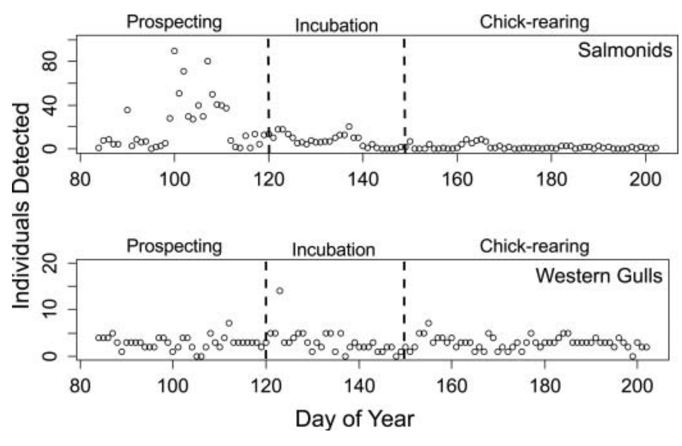


FIGURE 5. Number of individual PIT-tagged salmonid smolts and radio-tagged western gulls detected at Scott Creek between March 26 and July 21, shown by the day of the year. Out-migrating smolts (top panel) were detected by an instream PIT tag antenna installed 100 m upstream of the Scott Creek mouth, and radio-tagged western gulls (bottom panel) were detected by the Scott Creek automatic data collection system. Detections of salmonid smolts from March 30 (376 detections) are not included in the figure. The vertical dashed lines designate the phases of the western gull breeding cycle (prospecting, incubation, and chick rearing) that occurred during smolt out-migration.

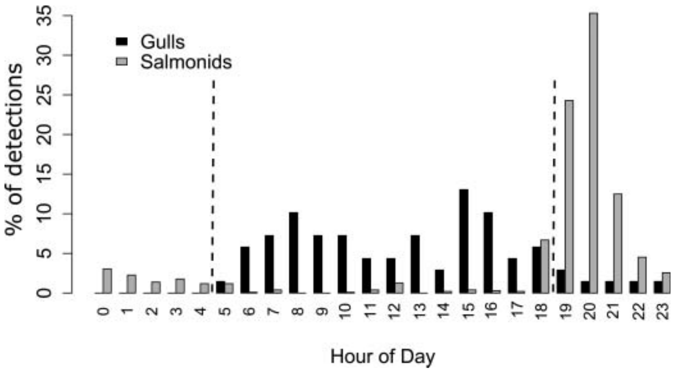


FIGURE 6. Detections of radio-tagged western gulls and PIT-tagged salmonid smolts per hour (expressed as the percent of total detections) at the Scott Creek mouth during peak smolt out-migration (March 26 to April 21). The vertical dashed lines designate day and night (sunrise was between 0527 hours and 0603 hours; sunset was between 1826 hours and 1848 hours).



the night (1900–0459 hours), whereas detections of western gulls by the Scott Creek ADCS primarily occurred during the day (Figure 6). The distribution of detections differed significantly between tagged western gulls and tagged salmonids (two-sample KS test: $P = 0.002$). Ninety-one percent of western gull detections and 11% of salmonid detections occurred between 0500 and 1900 hours. The greatest overlap occurred at dusk: 31% of fish detections and 9% of gull detections occurred between 1800 and 1959 hours. The length of day was relatively constant: sunrise ranged from 0603 hours on March 26 to 0527 hours on April 21 and sunset ranged from 1826 hours on March 26 to 1848 hours on April 21.

Most detections (64–98%) of western gulls at Waddell Creek occurred during daylight hours (0500–1900 hours) during all phases of the breeding cycle. The distribution of detections (Figure 7) during the course of the 24-hr period did not differ significantly between Scott and Waddell creeks during prospecting (two-sample KS test: $P = 0.840$), incubation ($P = 0.109$), or chick rearing ($P = 0.840$) but did differ significantly between the two sites postfledging ($P = 0.001$). During the postfledging period, radio-tagged western gulls were detected during all hours (24-hr clock) at Waddell Creek. At Scott Creek, however, 100% of detections occurred between 0600 and 1800 hours.

## DISCUSSION

We observed relatively little spatial and temporal overlap between western gulls and juvenile salmonids in central California watersheds. Concurrent estimates of predation rates of juvenile salmonids by western gulls, however, indicated that despite the little observed overlap, opportunistic predation by the Año Nuevo Island population of western gulls may have exceeded 30% of juvenile salmonids originating in these same watersheds (Osterback et al. 2013). The spatial extent of western gull movement was influenced by patterns consistent with central place foraging, with western gulls remaining closest to Año Nuevo Island during prehatch and chick rearing relative to postfledging. Temporal overlap between out-migrating salmonids and western gulls at Scott Creek largely occurred during dawn and dusk, as salmonids migrated primarily at night and gulls are visual predators and were present mainly during the day. Human disturbance at creek mouths may further limit overlap between gulls and salmonids at creek mouths and buffer predation.

During the prehatch and chick-rearing phases of the breeding cycle, detections of radio-tagged western gulls decreased with increasing distance from Año Nuevo Island, with the exception of trips to the landfill, likely for foraging. After fledging, the number of western gulls detected at Año Nuevo Island decreased markedly. Our results must be interpreted with some caution, as this study was confined to one breeding season and the western gulls included in this study exhibited individual diet variation (Osterback 2014). Our findings, however, are in accordance with attendance patterns of western gulls at southeast Farallon Island, the largest western gull breeding colony in California, approximately 90 km northwest of Año Nuevo Island. Spear (1988) found that nest attendance at southeast Farallon Island was greatest in April, corresponding to the start of egg laying, and that adults dispersed after chicks fledged in August and September. Like other populations, western gulls breeding on Año Nuevo Island exhibited central place foraging and were limited in the distance traveled and duration of foraging trips by the need to return to their nests to incubate eggs and feed and protect young from attacks from predators and conspecifics (Martindale 1982; Pierotti and Annett 1990, 1991).

Because western gulls breeding on Año Nuevo Island exhibited central place foraging and rarely were detected in watersheds south of Scott Creek, the risk of predation by the Año Nuevo Island population of western gulls was less likely for salmonids in the San Lorenzo River, Soquel Creek, and Aptos Creek than for salmonids in Gazos, Waddell, and Scott creeks (Figure 1). These results agree with the findings of previous studies of PIT tag recoveries on Año Nuevo Island, which demonstrated that tag transportation and deposition rates were greatest for tagged salmonids originating in watersheds closest to Año Nuevo Island (Gazos, Waddell, and Scott) and extremely low for watersheds farther from Año Nuevo Island (San Lorenzo, Soquel, and Aptos; Frechette et al. 2012; Osterback et al. 2013). Salmonids using these southernmost watersheds may experience a still-undetermined level of predation by nonbreeding western gulls and western gulls breeding south of Año Nuevo Island, for example those breeding at the wharf in Santa Cruz (Spear et al. 1986). Although fewer PIT tags have been deployed in salmonids in the San Lorenzo, Soquel, and Aptos watersheds (Frechette et al. 2012), scanning for PIT tags at the wharf in Santa Cruz may help improve estimates of predation for these creeks.

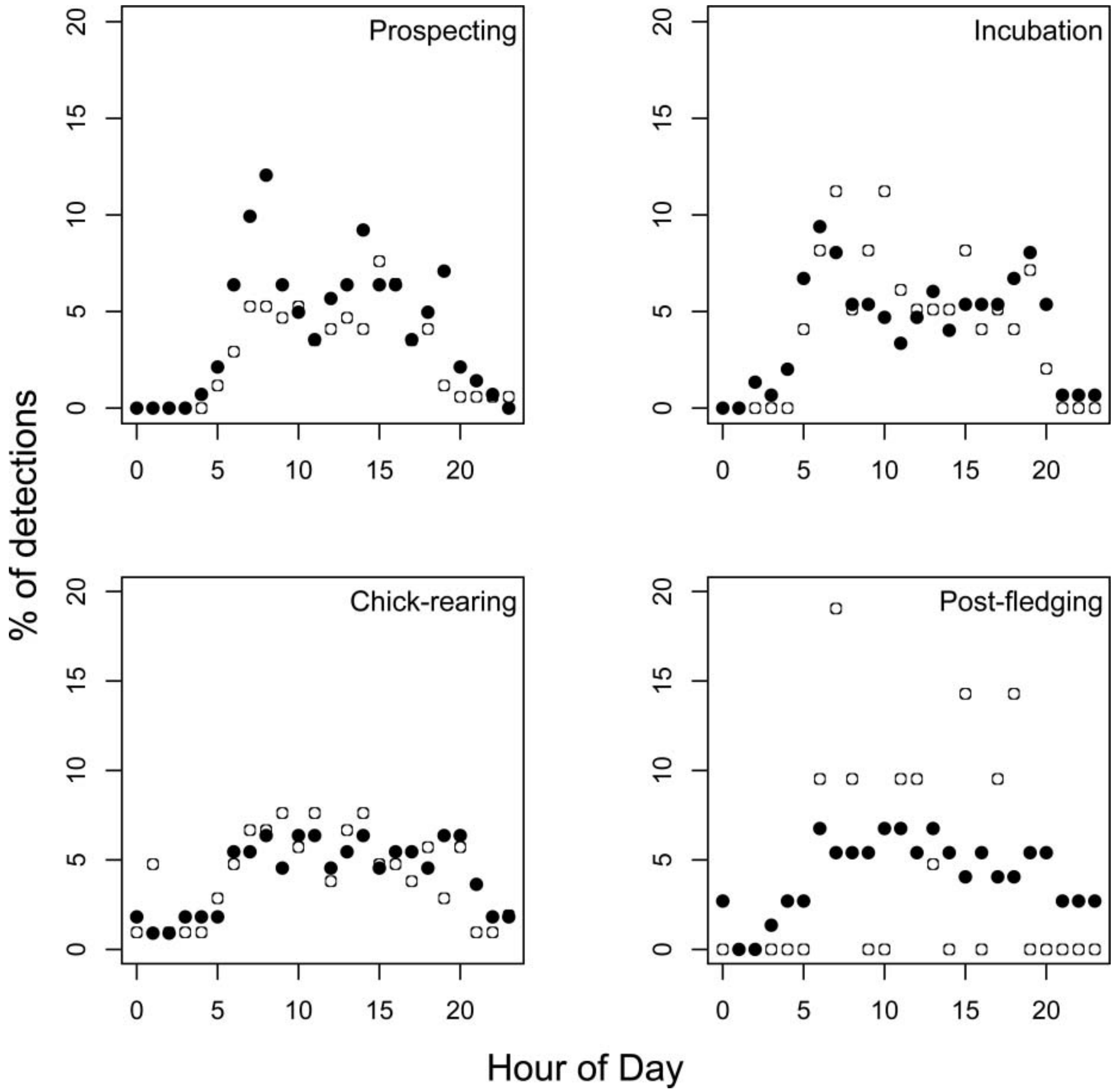


FIGURE 7. Detections of radio-tagged western gulls per hour (expressed as the percent of total detections) during each phase of the breeding cycle (prospecting, incubation, chick rearing, and postfledging) at Waddell Creek (filled circles) and Scott Creek (open circles).



During peak smolt out-migration, juvenile salmonids were most susceptible to western gull predation at dusk, when the greatest overlap occurred between western gulls and salmonids. 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 (Hayes et al. 2011). For the purposes of this study, however, peak smolt out-migration occurred during the prospecting phase of the western gull breeding cycle, and we have no reason to assume that smolt out-migration behavior differed between Scott and Waddell creeks (Hayes, unpublished). Further, because radio-tagged western gulls detected by the ADCSs at Scott and Waddell creeks included breeding adults, putative nonbreeders, and subadults, we believe that the detections of tagged birds were representative of the western gull presence at the creek mouths.

If western gulls had been targeting juvenile salmonids as prey, we would have expected the greatest use of creeks during smolt out-migration, which occurred during the prehatch phase of the breeding cycle. We observed the reverse pattern however: creek use increased during chick rearing, relative to the prehatch period (Figure 3). Further, if western gulls were targeting salmonids we also would have expected to see the greatest western gull presence at dawn and dusk, not during the middle of the day as we observed (Figure 6). The mismatch in time between fish movements and bird presence at creek mouths is likely a strategy by out-migrating juvenile salmonids to avoid predation by visual predators (Hansen and Jonsson 1986). Gull presence during the day may be explained by the availability of freshwater provided by central California creeks. Gulls were observed bathing and drinking in downstream portions of creeks throughout the year, regardless of whether salmonids were expected to be present (Frechette 2010). Gulls present when salmonids were available in the lower portions of creeks would be able to opportunistically prey on smolts as they migrated from freshwater habitat to the ocean.

The number of gulls present in and around the mouths of Scott and Waddell creeks decreased when humans were present; however, this pattern was only statistically significant at Scott Creek. Human disturbance was less prevalent at Waddell Creek than at Scott Creek and the low number of counts with disturbance at Waddell Creek likely explains the lack of statistically significant differences in mean gull counts with and without human disturbance. Since our observations were carried out over 6 d in 2009, further data collection may have led to more conclusive results. We did not measure the duration of each type of disturbance, but we noticed that kite surfers generally spent more time in and around creek mouths than surfers or people walking because of the amount of time it took them to set up and disassemble their kites before and after kite surfing. Further, kites remained an aerial disturbance in the ocean just offshore of the creek mouth for the duration of a kite surfing session and may have been perceived by the gulls as an aerial predation threat to themselves. With short duration disturbances, (e.g., a person walking though the creek mouth) gulls generally returned to the beach after the disturbance was gone but once a kite was in the air, gulls did not return. Although humans were present during all daylight hours at Scott Creek, the frequency of disturbance was greatest between 1000 and 1900 hours. Further work is needed to rigorously assess the effects of disturbance on gull presence at creek mouths; however, our data indicates that disturbance by humans, particularly kite surfers, during dawn and dusk (when the greatest overlap between out-migrating salmonids and gulls occurred), could reduce predation risk for juvenile salmonids.

The majority of radio-tagged western gulls were observed using the landfill (64%), suggesting that gulls from Año Nuevo Island may be influenced by anthropogenic food sources, thus acting as "subsidized predators." Anthropogenic food subsidies free predators from regulation by density-dependent effects, allowing populations to increase independent of natural prey availability (Gompper and Vanak 2008). High use of the landfill by tagged western gulls agreed with recent analysis of gull diet using stable isotopes and a mixing model. Using feather samples collected during gull tagging (this study), it was determined that despite some individual variation, the diet of western gulls captured at Scott and Waddell creeks had a diet consisting predominantly of human food (Osterback 2014). Further, recent data from GPS tags indicate that western gulls nesting on Año Nuevo Island make daily foraging trips to the landfill (S. A. Shaffer, unpublished). Combined, these studies indicate that the Santa Cruz landfill has likely subsidized the growth of the western gull population on Año Nuevo Island.

Predation by western gulls was not the sole driver of the recent population declines of federally listed salmonids in central California. Rather, declines were attributed to degradation of freshwater habitat, diversion of water for human use, and changes in oceanic productivity (Good et al. 2005). When predators are abundant and prey rare, however, even low levels of predation can negatively impact or prevent recovery of prey populations (Roby et al. 2003; Sanz-Aguilar et al. 2009). Recent estimates of predation rates, particularly for watersheds in closest proximity to Año Nuevo Island (Osterback et al. 2013), indicate that even minimal overlap between western gulls and steelhead produced predation rates in excess of 30% of the steelhead originating in central California watersheds. This level of predation was considered substantial for this depleted population because western gulls breeding on Año Nuevo Island predominately consumed lagoon-reared steelhead, the segment of the population that provides the greatest contribution to returns of reproductive adults (Bond et al. 2008; Frechette et al. 2012; Osterback et al. 2014). Recovery of salmonid populations near Año Nuevo Island may require either a reduction in the western gull population or deterrents to keep individuals from landing in creeks during periods of vulnerability (at dusk during peak smolt out-migration) and opportunistically eating salmonids.

The reduction of western gulls on Año Nuevo Island may be achieved indirectly through discouraging western gulls from foraging at the Santa Cruz landfill. Access to refuse dumps increases the survival of chicks to fledging and may also increase survival to adulthood (Weiser and Powell 2010, 2011). Thus, restricting access to the landfill may reduce future growth of the western gull population on Año Nuevo Island. Such measures were used to reduce corvid depredation on federally listed species in California deserts (Boarman 2003). Reducing foraging opportunities in the landfill will likely increase dependence on natural prey sources (Duhem et al. 2003; Ramos et al. 2009). Any measure to reduce western gull foraging at the landfill must be accompanied by direct measures to prevent western gulls from shifting foraging effort to streams where salmonids are vulnerable to predation.

The fidelity of western gulls to foraging and breeding sites may provide managers with additional tools for reducing the breeding population of western gulls on Año Nuevo Island. Removal of "repeat predators" can be more cost effective, less time and personnel intensive, and more palatable to the public than large-scale culling (Sanz-Aguilar et al. 2009). Instead of culling the Año Nuevo Island breeding colony, it may be more effective to remove gulls from watersheds where predation is greatest (Gazos, Waddell, and Scott watersheds). Our observation that gull presence around creek mouths decreased in the presence of kite surfers suggests that, in the absence of culling, sustained deterrence of gulls at creek mouths (possibly incorporating aerial deterrence, e.g. kites) during periods of peak overlap between gulls and out-migrating salmonids might offer a promising mitigation strategy to reduce predation and aid recovery of central California Coho Salmon and steelhead.

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