

Depredation of the California Ridgway's Rail: Causes and Distribution

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ABSTRACT: We studied the causes of mortality for the California Ridgway's rail at multiple tidal marshes in the San Francisco Bay Estuary, California. We radio-marked 196 individual rails and examined the evidence from 152 recovered California Ridgway's rail mortalities from our radio-marked sample and determined plausible cause of death from a wide array of evidence. We also included 10 additional California Ridgway's rail mortalities (unmarked) that we encountered during our normal field operations. We assigned a likely cause of death to 130 of the recoveries, of which 127 were determined to be caused by predation. Of those, 103 could be divided into class of cause (avian or mammalian), and avian predators were responsible for 64% of those events. Primary predators identified include domestic or feral cats, red fox, owl, and northern harrier. We did find seasonal differences between avian and mammalian predation rates, with higher proportions of avian predation in the winter and early spring. Time of day and tide height were correlated with predation events, with a greater proportion of known mortalities found during periods of high tides (over 60% marsh inundation) and during daylight hours. Predation is the primary source of mortality for California Ridgway's rail. Management actions that try to reduce avian predation may be the most effective at improving rail survival rates, given the proportion of avian predation detected.

KEY WORDS: California Ridgway's rail, endangered species, feral cats, mortality, predation, radio telemetry, rail, *Rallus obsoletus obsoletus*, San Francisco Bay, tidal marsh

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INTRODUCTION

The California Ridgway's rail (*Rallus obsoletus obsoletus*), formerly the California clapper rail (*R. longirostris obsoletus*; Chesser et al. 2014), is a secretive marsh bird endemic to intertidal salt and brackish marshes in the San Francisco Bay (SF Bay). At the turn of the 19th century, the California Ridgway's rail (California rail) was abundant in wetlands throughout SF Bay (Cohen 1895) and could also be found in Humboldt Bay (Gill 1979, Grinnell and Miller 1994), Elkhorn Slough (Silliman 1915), and Morro Bay (Bond et al. 1940). However, urbanization of SF Bay over the past century has resulted in significant changes to the adjacent tidal wetlands (Nichols et al. 1986, Takekawa et al. 2006). Given the extent and severity of these changes, less than 10% of the San Francisco Bay's historical tidal saltmarsh remains (Monroe et al. 1999).

By the early 1970s, the combined effects of conversion of tidal marsh to diked lands for agriculture and salt production (Monroe et al. 1999); urban encroachment (U.S. Fish and Wildlife Service 2013); predation by both native and non-native predators (Harding et al. 2001); and impacts from contaminants such as mercury (Schwarzbach et al. 2006, Ackerman et al. 2012) put the California rail on

the endangered species list with as few as 2,000-5,000 California rails remaining (USFWS 2013). The population continued to decline into the 1990s to fewer than a thousand individuals (CDEG 2008) due, in part, to predation by non-native red fox (*Vulpes vulpes*) (Albertson 1995, Foin et al. 1997, Harding et al. 2001). Subsequent predator management and habitat restoration projects were undertaken to stabilize California rail populations in the remaining tidal wetland habitats in the late 1990s and were credited with increasing the California rail population in SF Bay to over a thousand individuals (Albertson and Evens 2000).

The California rail is dependent on refuge cover during high tides for protection from predation. While the subspecies' population dynamics are poorly understood (Liu et al. 2012), recent work has estimated low annual survival rates (27-47%) in south SF Bay marshes (Overton et al. 2014). Radio-telemetry studies have found that California rail survival rates were lowest when tide heights were greatest and during the winter when much of the intertidal vegetation used as refuge habitat (e.g., *Spartina* spp.) had senesced (Albertson 1995, Overton et al. 2014). Concurrent with the aforementioned predator control



Figure 1. Location of eight tidal marshes throughout San Francisco Bay where California Ridgway's rails were captured and radio-marked between 2006 and 2014.

efforts, an invasive hybrid cordgrass, *Spartina foliosa* × *alterniflora*, which grows taller and more densely than native vegetation, spread throughout southern SF Bay (Daehler and Strong 1997, Grosholz et al. 2009). The increased vertical structure of the hybrid *Spartina* increased the availability of refuge habitat for the California rail, especially during vulnerable high tide periods, and resulted in increasing populations prior to the on-going hybrid *Spartina* eradication program (McBroom 2012, Overton 2013).

In this study, we investigate rates of predation on California rails by a range of native and non-native predators in eight tidal marshes throughout San Francisco Bay between years 2006 and 2014. We recovered mortalities of radio-marked California rails and determined probable cause of death through examination of remains and immediate surroundings, and through necropsy and tissue cultures. From these observations, we examine patterns in predation rate of California rails in relation to marsh location, predator type, tide height, and time of year. Based on the observed patterns in these variables, we discuss what the resulting trends suggest in terms of management actions for the California Ridgway's rail.

METHODS

Study Sites and Capture Methods

Between December 2006 and March 2014, and in

conjunction with prior research on California rail survival (Overton et al. 2014), we captured and radio-marked 196 California rails in eight marshes throughout SF Bay (Figure 1). Initial capture efforts were focused in Central [Arrowhead/Martin Luther King, Jr. (MLK) Marsh and Colma Marsh] and South SF Bay (Cogswell Marsh and Laumeister-Faber Marsh). Beginning in 2012, we expanded capture efforts to include several North SF Bay marshes [Corte Madera Ecological Reserve (CMER), Gallinas Creek-McInnis, and Petaluma River-Carl's Marsh]. The geohydrology of the marsh determined which capture methods we used. Capture in higher-elevation marshes with well-developed tidal channels involved Tomahawk® live-traps in two different sizes (107×38×41 cm or 41×13×13 cm). These traps were modified by removing the treadle mechanism typically used to trigger the trap and replacing it with a tripwire attached to an externally-mounted spring-snap rat trap. The snap-bar of the rat trap was attached to the Tomahawk® trap door-release mechanism allowing the live-trap doors to close when pressure on the tripwire triggered the rat trap. The modified live traps were placed at low tide within channels (Figure 2) and passively caught California rails as they moved through and foraged in tidal channels. At lower-elevation marshes where the majority of tidal refuge habitat was completely flooded during spring tides, we caught California rails by hand or dip-net, either on foot or from boats during high tides. Remaining unflooded habitats were surveyed by foot for hiding California rails, which were either caught by hand upon discovery or flushed toward open water, where small boats using electric trolling motors would track down swimming California rails and capture them using dip nets. Only two marshes, Colma Marsh and Arrowhead Marsh, flooded sufficiently for the high tide capture method. Capture efficiency was much greater where the high tide capture technique could be used, but suitable locations for this methodology are uncommon in SF Bay.



Figure 2. A Tomahawk® live trap (107 × 38 × 41 cm) modified by replacing the treadle mechanism with a tripwire attached to an externally-mounted spring-snap rat trap. Placed at low tide within channels, they passively caught California Ridgway's rails as they moved and foraged through the marsh.



Figure 3. A California Ridgway's rail, fitted with a backpack-mounted very-high frequency (VHF) radio transmitter.

We fitted captured California rails with backpack-mounted very-high frequency (VHF) radio transmitters (Model A1120, Advanced Telemetry Systems, Isanti, MN). The radio transmitters weighed approximately 9.3 g, and we attached a transmitter to each California rail via a Dwyer harness (Dwyer 1972) made of 3/16-inch tubular Teflon[®] ribbon (Figure 3). Radio transmitters were equipped with four-hour mortality sensors that doubled the pulse rate of radios after four hours of immobility, usually indicating mortality or extended periods of loafing.

Telemetry

We used three-element handheld Yagi antennas and Advanced Telemetry Systems receivers (Model R4500SD) to locate signals from radio-marked California rails. We generally triangulated locations of radio-marked rails by using a handheld compass and recording azimuths directed at points that produced strongest signals from three to six locations (recorded with handheld GPS units). Observer locations and azimuths were analyzed using LOAS Version 3.0 (Ecological Software Solutions, LLC) or Locate III programs (Pacer Computing, Tatamagouche, NS, Canada) using Maximum Likelihood Estimators to obtain coordinates and error estimates for the rails' locations. When a radio-marked rail was visually observed, we estimated the rail's location using orthorectified aerial photos and relevant local landmarks (e.g., vegetation patches, forks in tidal channels). In some marshes where close access (<50 m) and limited habitat enabled direct estimation of radio-marked rail locations (e.g., Colma Marsh), we used orthorectified aerial photos and pinpointed rail locations in the field based on direction of the signal, landmarks, and observer location. When radio signals abruptly disappeared from a marsh, we first scanned for frequencies in adjacent habitats. If these searches were unsuccessful, then we employed aerial telemetry techniques from fixed-wing aircraft to search throughout coastal marshes within SF Bay for missing frequencies. Aerial telemetry was responsible for relocating three of the four California rails that emigrated from the marsh where they were initially caught and marked.

Timing of Mortality and Tidal Conditions

In addition to location estimation using handheld telemetry, we deployed data-logging VHF receivers at Arrowhead Marsh between years 2010 and 2014; at Colma Marsh between 2009 and 2010; and Faber, Corte Madera, and Gallinas Creek Marshes in 2012 and 2013. These receivers were powered either by solar panels and a 12-volt deep-cycle battery (most marshes), or were charged on-site from a 110-volt AC outlet (Arrowhead Marsh only). We programmed the receivers to scan through radio frequencies of radio-marked California rails every 15 minutes and record the pulses per minute and strength of the radio signal. Any transmitter pulse rate and signal strength detected by the data-logging receivers were later used to identify the precise period when mortality occurred.

The strength of a transmitting radio is typically highly variable, as the individual California rail moves through the marsh and forages along channels. Patterns of signal strength become less variable when the transmitter is lying motionless, even before the mortality switch activates the change in pulse rate. Tidal inundation also attenuates the signal from transmitters covered by the incoming tide, and we used these characteristics to further indicate when death occurred (Figure 4).

Multiple factors resulted in a discontinuous data record obtained by the data-logging receivers. Prolonged periods of cloudy or foggy weather occasionally resulted in insufficient charge through the solar panels to maintain operation of the receivers. Components of the data logging system (i.e., charger, data-logging receiver, Yagi antenna, coaxial cable, solar panel, and a box housing the electronics) were also subject to vandalism. Despite these problems, data-logging receivers helped identify the timing of mortality for 11 individual California rails and provide insight into California rail behavior and circadian activity patterns.

Determination of Cause of Mortality

We investigated 162 California rail mortalities to determine the cause of death. These included 152 radio-marked individuals and ten unmarked individuals found in or near the marsh. Carcasses of radio-marked California rails were retrieved as soon after detection of mortality as tidal conditions allowed so as to minimize opportunities for multiple predators and scavengers to encounter the carcasses before retrieval by researchers. Carcasses of unmarked California rails were found serendipitously while researchers were in the marsh for other fieldwork purposes. Determining the proximate cause of mortality is a subjective exercise in the absence of definitive evidence; nevertheless, subjective determination of causes can provide important direction for predation mitigation efforts. Available evidence at the location where carcasses/transmitters were recovered was used to identify potential causes of mortality. Many carcasses, for which there was insufficient physical evidence to determine cause, were sent to the USGS National Wildlife Health Center in Madison, WI for necropsy. Detailed examination of the carcass and location where the carcass was

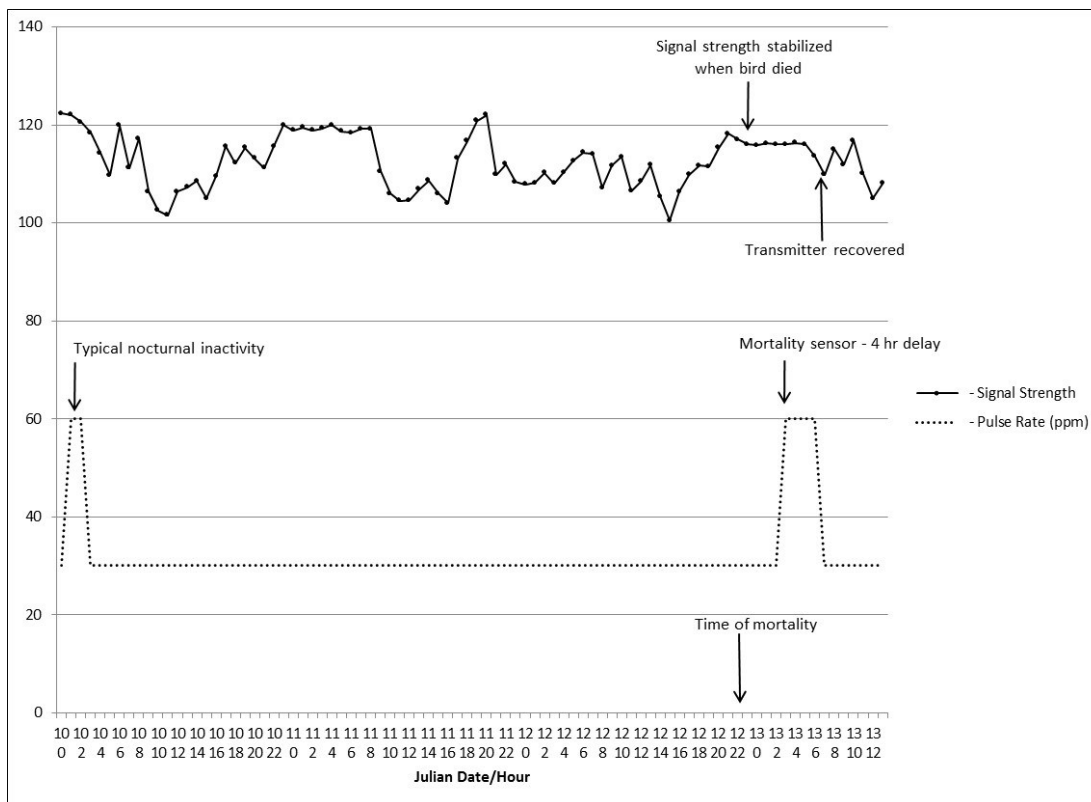


Figure 4. Examples of data recorded by automatic data-loggers on both individual activity patterns and time of death through recording of transmitter signal strength and presence of a mortality signal (pulse rate) from the radio-transmitters.

recovered was used to identify cause of mortality as mammal predation, avian predation, disease, or unknown using the following criteria:

Mammal Predation: carcass and transmitter recovered on the ground including from underneath dense shrub vegetation, significant damage to large bones, crushed or torn feathers, widely scattered remains, and tooth marks on or severe damage to transmitter;

Avian Predation: carcass and/or transmitter recovered from elevated position (tree, powerlines, fence, etc.), definitive pluck pile of feathers, feather pulled individually or in small groups with no discernable damage, only breast meat eaten with remainder of carcass intact;

Disease: only identified through necropsy and tissue cultures; and

Unknown: carcasses could not be recovered, radios failed, or no substantial evidence (e.g., lack of visible mortal wounds) was available for inference.

In many instances, we were able to identify the predator species, or combined Strigidae/Tytonidae family group in the case of owls, suspected of causing the mortality. Our assessment of the specific agent responsible for mortality was highly conservative, and we only assigned predator species or group when the evidence pointing to one was extensive. We attributed depredations by predator based on the following criteria:

Cat Predation (*Felis catus*): carcass removed from the marsh or within 10 meters of a surrounding levee, damage only evident to the neck or base of the skull (Lyver 2000; Figure 5), and carcass not eaten, or carcass recovered

adjacent to feral cat feeding stations where multiple bird species carcasses were recovered;

Red Fox Predation (*Vulpes vulpes*): carcass buried in location known to be occupied by red fox;

Owl Predation (Family Strigidae/Tytonidae): brain case removed (often this was the only damage to the carcass occasionally with soft organs also removed); and

Northern Harrier Predation (*Circus cyaneus*): carcass recovered adjacent to or from within an active northern harrier nest.

RESULTS

We were able to recover 152 radio-marked rail carcasses and ten unmarked rail carcasses, which were investigated to determine the specific cause of mortality for California rails in SF Bay (Table 1). Sufficient evidence allowed us to deduce the fate of 130 California rails, and predation was determined for 127 (78%) mortalities. Over 90% of depredations could be assigned to the class of predator ($n = 103$). On average, avian depredation was twice as prevalent as mammalian depredation; however, this ratio varied throughout the year. Between October and April, the proportion of California rails depredated by avian predators was higher than mammal predation on California rails, with the trend reversing in July and August (Figure 6). During May and June, mammal and avian depredation on California rails was proportionally equal. Confirmed avian predation was proportionally lowest in August, and mammal predation was highest in September.



Figure 5. Three California Ridgway's rails that were determined to be preyed by feral cats.

Our data-logging receivers at Arrowhead Marsh recorded enough transmitter pulse rate and signal strength data for us to investigate the timing of mortality for 11 radio-marked California rails relative to the height of the tide (Figure 7), and we found higher percentages of the mortalities to be associated first with the time of day and second with tide stage. The greatest percentage (55%) of these Arrowhead Marsh mortalities occurred during the early afternoon; three mortalities (27%) occurred at night and two (18%) occurred in late morning. A disproportionate number of these mortalities (55%; $n = 6$) occurred during 1.6+ meter tide events that inundated the marsh plain and covered much ($\geq 60\%$) of the marsh area vegetation; a phenomenon that occurs only 20% of the time at Arrowhead Marsh. Thus, a disproportionate number of California rail mortalities occurred during daytime periods when the marsh plain (and refuge habitat) was inundated by tides.

Regardless of seasonality or time of day, we found differences in occurrence of causes of California rail mortality from site to site across SF Bay (Figure 8). Mammalian and

Table 1. Radio-marked California Ridgway's rail mortalities collected in San Francisco Bay, 2007-2014.

| MORTALITY CAUSE | |
|--------------------------------|-----|
| Predation | 127 |
| Avian Predation | 66 |
| Northern Harrier | 1 |
| Owl Species | 8 |
| Mammal Predation | 37 |
| Red Fox | 3 |
| Feral Cat | 11 |
| Unknown Predation | 24 |
| Disease | 3 |
| Avian tuberculosis | 1 |
| <i>Vibrio parahaemolyticus</i> | 2 |
| Unknown | 32 |

avian-caused predation was approximately equal at Lau-meister, Cogswell, and Carl's Marsh. Mortalities among the remaining five marshes that could be assigned to particular predators were three times more likely to be caused by avian predators than mammalian predators. For two sites in the North SF Bay (Gallinas Creek-McInnis Marsh and Corte Madera Marsh) avian predation represented a distinctly large component of predation events, matched only by Faber Marsh in the South SF Bay. The South SF Bay had a greater number and geographic spread to its sites than the North SF Bay (Figure 1) and also had depredation by a greater variety of predators, most notably feral cats (Figure 8). To that point, feral cats were identified as California rail predators in all five South Bay sites except Cogswell Marsh ($n = 11$ of 37, Table 1). Feral cats were a particular issue at Colma Marsh, where they accounted for 25% of the confirmed predation events, and cat kills represented close to 30% of the total known mammal-caused predation events affecting California rails in SF Bay.

Our predation results demonstrate a geographic separation in the effective predator community impacting California rails (Figure 9). Avian predation was relatively constant across the 3 North Bay sites (Figure 8) and averaged over 50% within the North SF Bay (Figure 9). But in the South Bay, avian predation was more varied and ranged from 25% to 60% (Figure 8). The total South SF Bay percentage averaged to 38% (Figure 9). Over 90% of the mammal-caused predation events on California rails were recorded in South SF Bay, where they represented nearly 25% of total mortality causes, whereas only three of the total mammal predations were recorded in North SF Bay.

DISCUSSION

Causes of Mortality

The primary cause of mortality for California Ridgway's rail was predation. Disease, at least during the time of our study, played only a minor role as a mortality occurrence ($n = 3$). We were unable to determine the cause of death in slightly over 20% of the mortality events; however, it is likely that predation made up a significant proportion of those occurrences, given the limitations of periodic re-location of radio-marked individuals via hand-held telemetry observations.

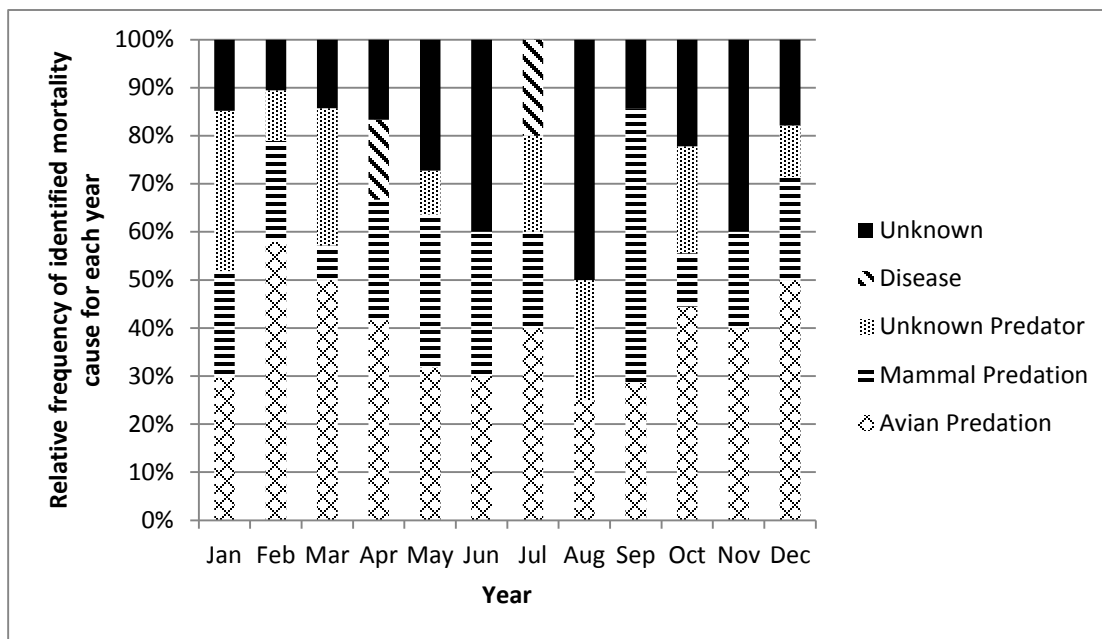


Figure 6. Probable causes of California rail mortality in SF Bay, 2007-2014 by month of year.

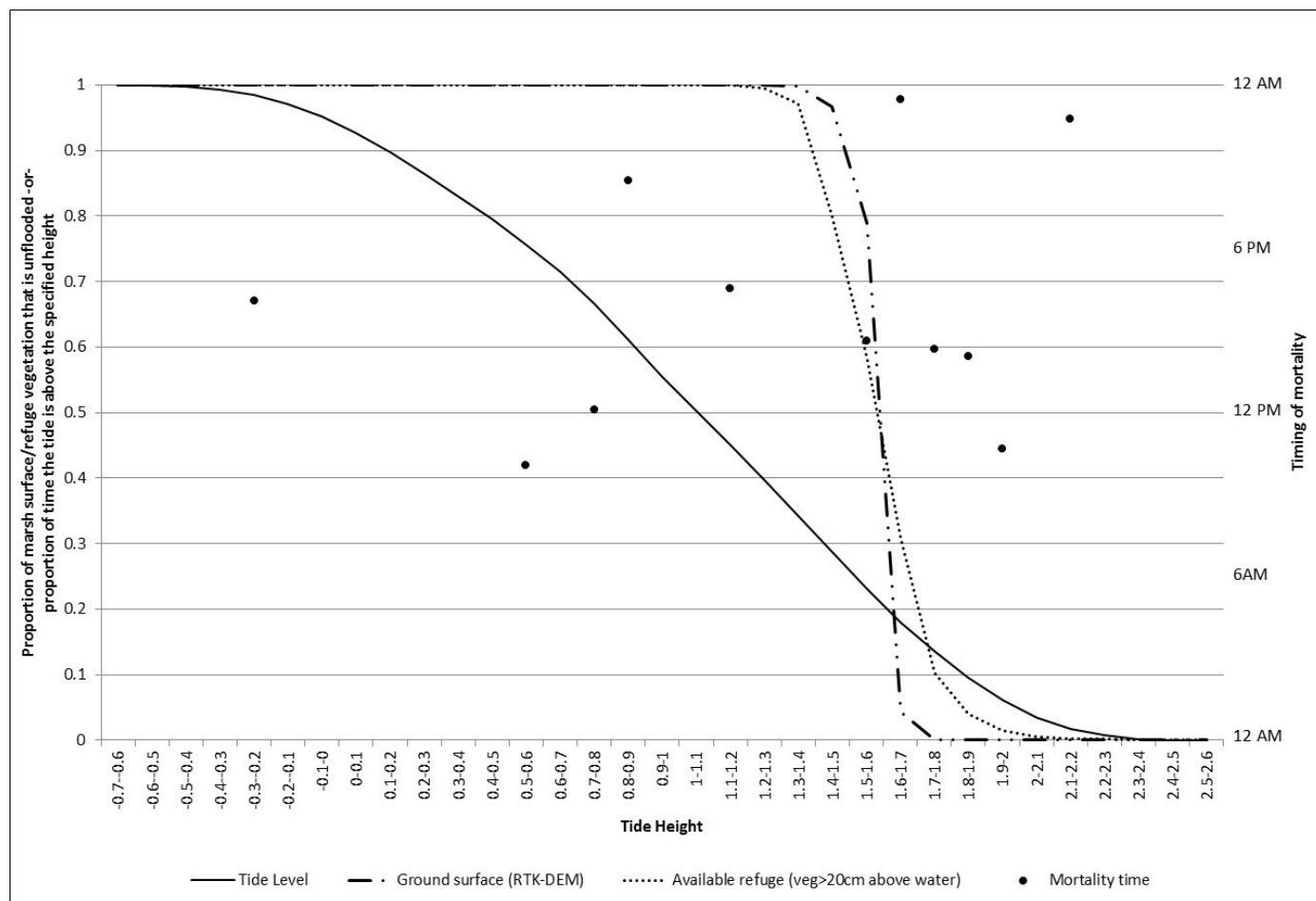


Figure 7. Time of death information obtained from a data-logging receiver placed at Arrowhead Marsh was compared to coincident tide conditions and refuge habitat availability.

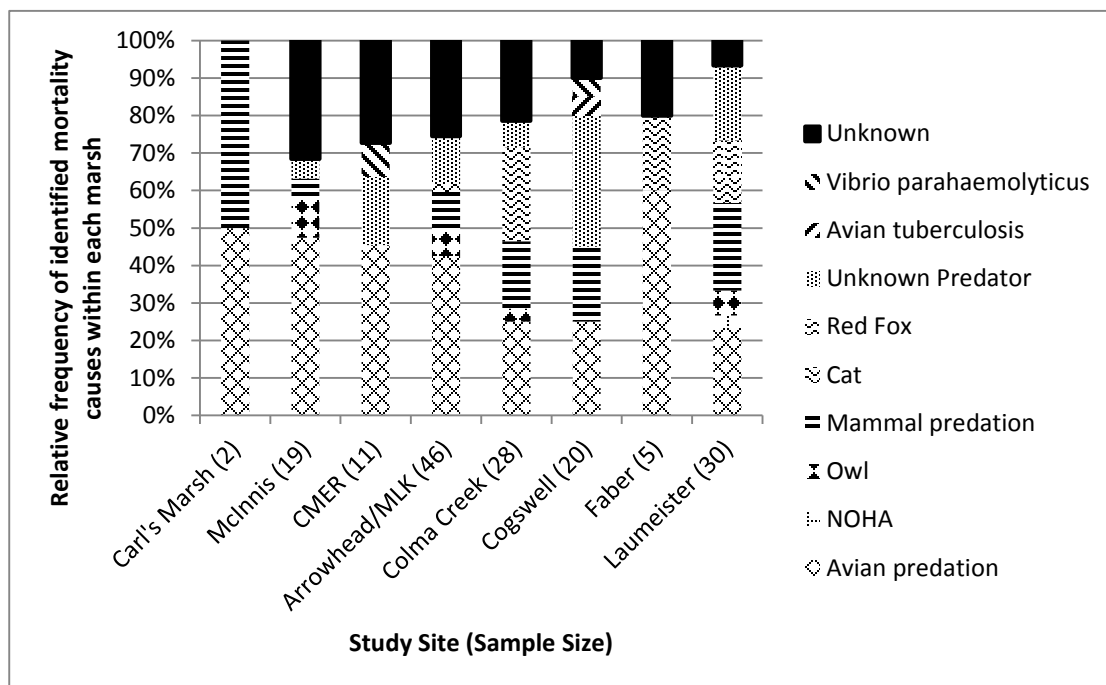


Figure 8. Percentages for causes of mortality of radio-marked California Ridgway's rails at 8 San Francisco Bay sites.

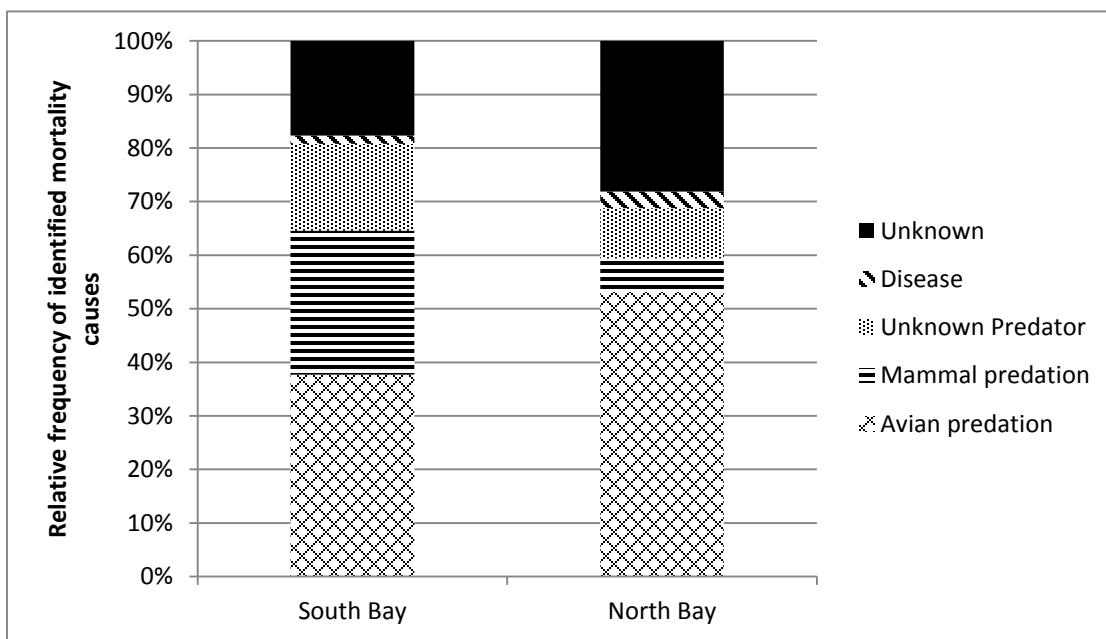


Figure 9. Mortality cause ratio for all South San Francisco Bay sites and all North San Francisco Bay sites.

Avian Predators

Avian predators accounted for the majority of recorded California rail mortalities, suggesting that finding ways to reduce their occurrence near areas with high California rail densities may increase survival. Though tidal marshes do not commonly contain many natural structures that could serve as perch, roost, or nesting sites for avian predators, human activities within or adjacent to marsh habitat can

help facilitate avian predation on California rails through the provision of artificial perch structures, such as electrical towers, wooden boardwalks, and rooftops. Similarly, the presence of anthropogenic features in sagebrush ecosystems has been found to be an important predictor of nesting raptor and raven distribution (Coates et al. 2014), which can in turn affect greater sage-grouse reproductive success (Bui et al. 2010). Limiting the

construction of artificial perch structures within or near tidal marshes could reduce avian predation on California rails.

Mammalian Predators

Study sites in South SF Bay had a greater occurrence of mammal-caused predation than sites in North SF Bay. The South SF Bay sites spatially correlate with hotspots of SF Bay urbanization (Clarke et al. 1997). As cityscapes break contiguous natural habitats into fragments, the rate of mammalian predation is predicted, and has been shown, to increase (Crooks and Soule 1999). In fact, the inverse of isolated habitat hectares is rated as the best predictor of feline predation in an urban environment, presumably because of increasing edge exposure to housecats (Crooks and Soule 1999). This aligns with our site-to-site cat-specific results for the five South SF Bay sites: Arrowhead/MLK, Colma Marsh, Cogswell, Faber, and Laumeister Marshes (Figure 8). We noted two particularly dense feral cat colonies near the Faber/Laumeister complex and the Colma Marsh study sites (USGS unpubl.). Predation by domestic cats (either owned or unowned) has been identified as a significant contributor to avian mortality across the United States, with an annual take estimated at 2.3 billion birds (Loss et al. 2013). This further contributes to the mammalian predation discrepancy between our less-urbanized North SF Bay and South SF Bay study site (Figure 9).

While cat kills make up 11 of the 37 recorded mammal predation events, other non-native predators are represented within the remaining 26 events classified as mammalian (Table 1). As the red fox removal efforts of the 1990s (Albertson and Evens 2000) precedes our data, we neither expected nor saw a notable red fox problem. Only three Laumeister Marsh predations are red fox-specific (Table 1, Figure 8). The Crooks and Soule note (1999) presents the idea of a fragment area threshold for dominant native predators like coyotes, and fragmentation of the SF Bay has severely reduced suitable area of tidal marsh habitat (Albertson and Evens 2000). Fragments of South Bay habitat might become too small to support mammals (native or not) other than cats, which have supplemental food sources.

Light Pollution

Over a quarter of California rail mortalities at Arrowhead Marsh, for which timing data are available, occurred at night. Past research has shown that California rails are least active at night, sometimes to the point of falsely triggering the four-hour mortality sensor (U.S. Geological Survey, unpubl.; Figure 4). The purpose of this behavior pattern may be to avoid detection by predators, particularly mammalian predators, during this susceptible time period. However, increasing levels of artificial light (International Dark-Sky Association, www.darksky.org) may make California rails more vulnerable to night-time predation by increasing their detectability. This is most likely to occur at highly urbanized sites such as Arrowhead Marsh and Colma Marsh, which are adjacent to the Oakland and San Francisco International Airport, respectively, and are thus regularly inundated with artificial light. Light pollution has been shown to increase night-time predation levels of

several prey species, either through the attraction of prey to well-lit areas, or through the disorientation of prey in such areas, where they are then more likely to be detected by predators (Clarke 1983, Canario et al. 2011, Minnaar et al. 2015). Anti-predator behaviors that once served to protect prey species at night may now be rendered less effective, as humans continue to alter natural light conditions on a global scale.

CONCLUSION

The discrepancy in California rail mortality by predator type (avian vs. mammalian) between North SF Bay and South SF Bay is likely a result of varying predator communities in response to the highly urbanized South SF Bay region. Management programs which reduce feral cat populations may be warranted in marshes with significant urban edge. Seasonal patterns in the causes of mortality suggest increased effectiveness of avian predators in the winter and increased effectiveness of mammalian predators during the late portion of the breeding season. The lack of winter cover may be contributing to the high avian predation rates during this time period (Overton et al. 2014). Given predictions for sea level rise in the SF Bay region, this problem will likely be exacerbated in the future. Efforts to reduce tall anthropogenic structures (power lines, towers, etc.) may help to reduce avian predation effects in the future. Tidal marsh restoration efforts that provide vegetation structure which provides high tide refugia may also be important in reducing avian predation. Minimizing light pollution may also help to reduce the relative risk of predation, especially at night. Further research which documents demographic rates and predator composition will help to inform long term population management of this species.

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