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Waterbird Susceptibility to Avian Cholera at Hayward Marsh, California, USA

Amy K. Wray,[1,2,3] Douglas A. Bell,[1] Peter Dramer,[1] and Mark Taylor[1] [1]East Bay Regional Park District, 2950 Peralta Oaks Court, Oakland, California 94605, USA; [2]Department of Ecology, Evolution, and Environmental Biology, 1200 Amsterdam Avenue, Columbia University, New York, New York 10025, USA; [3]Corresponding author (email: aw2812@columbia.edu)

ABSTRACT: We characterized past avian cholera outbreaks in waterbirds at Hayward Marsh, California, US. In 2013, we surveyed populations and determined the presence of disease using several diagnostic methods, including behavioral and physical observations, field necropsy, and bacterial culture. We compiled this information with data from previous outbreaks from 1990–2012 to compare waterbird abundance to various measures of mortality, including percentage of mortality and percentage of difference between abundance and mortality by species. We suggest that Ruddy Duck (*Oxyura jamaicensis*) have consistently suffered greater mortality from this disease than have other species at this site.

Key words: Avian cholera, Hayward Marsh, *Oxyura jamaicensis*, *Pasteurella multocida*, susceptibility, waterbird.

Avian cholera is a devastating disease caused by the gram-negative bacterium *Pasteurella multocida* (Friend 1999; Samuel et al. 2007). Although avian cholera is one of the most important diseases of waterbirds, the environmental parameters associated with outbreaks are not well defined. The environment can provide a short-term reservoir for *P. multocida* (Bredy and Botzler 1989; Botzler 1991), whereas infected birds may serve as long-term reservoirs (Samuel et al. 2004; Blanchong et al. 2006). Certain waterbird species may have a disproportionate effect on disease transmission (Samuel et al. 2005a, b), with mortality trends varying among years and sites (Mensik and Botzler 1989). Infection with avian cholera has also been associated with variations in waterfowl population density, habitat use, and feeding behavior, in addition to physiologic susceptibility (Combs and Botzler 1991). Here, we characterize the history of avian cholera outbreaks at Hayward Marsh, California, US, by comparing mortality rates with abundance of live populations and by examining species susceptibility.

Mortality from avian cholera correlates with neither waterbird population size nor average body weight (Rosen 1969). To better understand and mitigate the spread of avian cholera, as well as to predict when and where future outbreaks are likely to occur, we must develop management strategies based on the characteristics of each specific outbreak site and the dynamics of its waterfowl populations.

Hayward Marsh (37°38′N, 122°08′W) is a 60-ha perennial wetland located within Hayward Regional Shoreline, a unit of the East Bay Regional Park District in Alameda County, California, US. Since 1990, Hayward Marsh has experienced at least 12 reported avian cholera outbreaks, occurring between December and April. Carcasses were systematically removed and recorded for all subsequent outbreaks at this site, with species and location recorded for any identifiable carcasses. Of particular interest to us, because of their apparent high mortality rates, were the Ruddy Duck (*Oxyura jamaicensis*), American Coot (*Fulica americana*), American Wigeon (*Anas americana*), Northern Shoveler (*Anas clypeata*), and Bufflehead (*Bucephala albeola*), although other bird species were also present.

To summarize the history of avian cholera at this site, we analyzed waterbird abundance and mortality data from avian cholera outbreaks that occurred from 1990 through 2012. These data had been collected by wetland biologists and other East Bay Regional Park District staff, with species and location recorded for all identifiable carcasses. During that period, ducks, coots, and geese consis-

tently comprised more than 80% of the total mortality; consequently, we examined differences in the percentage of abundance and percentage of mortality by species within these groups only.

For the 2013 avian cholera outbreak, we conducted waterbird censuses using a standardized transect survey method (Hostetler and Main 2014). We collected diseased and deceased birds during all-area searches conducted three to five times per week during the 2013 outbreak. We took live birds with signs of acute avian cholera infection to a nearby wildlife rehabilitation center for treatment. Observed clinical signs of avian cholera infection in live birds included swimming in circles, throwing the head back between the wings, erratic flight, convulsions, and rapid death upon capture, without signs of emaciation.

We substantiated positive diagnoses by field necropsy and the presence of at least two of the three factors listed by the US Geological Survey *Field Manual of Wildlife Disease* as indicative of avian cholera: heart muscle hemorrhage, lesions and necrotic tissue on the liver, and thick, yellow fluid in the intestine (Friend 1999; Green et al. 2012). We sent four carcasses to the California Department of Fish and Wildlife (CDFW) Wildlife Investigations Laboratory in Rancho Cordova, California, US, for diagnosis via full necropsy. Presence of *P. multocida* bacteria was confirmed via blood smear staining with Wright's One-Step stain (Medical Chemical Corporation, Torrance, California, USA) and bacterial isolation and identification according to University of California, Davis, protocols (Jang et al. 2008). All four carcasses, which included Ruddy Duck (n=3) and Northern Shoveler (n=1), were positively diagnosed with *P. multocida*–induced septicemia, with *P. multocida* detected in lung and liver swabs.

We used a Kruskal-Wallis rank sum test to compare the percentage of abundance and the percentage of mortality among bird species. We also used generalized linear models (GLMs) to compare mortality in the Ruddy Duck with the total abundance and total mortality of all waterfowl. However, the number of carcasses collected does not necessarily reflect the species that are most affected by this disease because waterbird mortality from other causes may complicate outbreak assessment.

We calculated average abundance as the average live population from previous population surveys, with the percentage of abundance calculated as the respective abundance of each species divided by total waterfowl abundance. We calculated average mortality as the average number of diseased or deceased birds collected, with the percentage of mortality calculated as the respective mortality of each species divided by total waterfowl mortality. To determine whether a species was differentially affected by the disease, we compared the percentage of mortality for each species to its respective abundance (Botzler 2002). For the years in which avian cholera outbreaks occurred, there were five outbreaks in which both mortality data and population estimates were available.

Twelve avian cholera outbreaks with at least 70 identified carcasses per event were recorded at Hayward Marsh from 1994 to 2013. For these outbreaks, Ruddy Duck represented the most carcasses collected, followed by Northern Shoveler and American Coot. American Wigeon also made up a large proportion of collected carcasses in 2000 and 2009 (Table 1).

Species was a significant predictor of the percentage of abundance and percentage of mortality among waterbirds (Kruskal-Wallis test, df=9, $P<0.001$; Fig. 1). There was a significant relationship between abundance and species mortality (GLM, df=48, $P<0.001$) among all species included in the study. For Ruddy Duck, in particular, species mortality correlated with total mortality (GLM, df=3, $P<0.01$), although percentage of abundance did not correlate with total abundance (GLM, df=3, $P=0.108$). These results suggest that although the total number of waterbird deaths resulting from avian cholera often varies among outbreaks at this site, mortality rates may be somewhat consistent among certain waterbird species.

TABLE 1. Number of waterfowl carcasses collected during seasonal avian cholera outbreaks at Hayward Marsh, California, USA, from 1990–2013. Asterisks indicate years for which abundance data were also available.

Year	American Coot	American Wigeon	Bufflehead	Canada Goose	Gadwall	Mallard	Northern Shoveler	Ruddy Duck	Other waterbird	Total
1990	0	2	0	0	0	0	46	26	1	75
1994	27	14	0	12	15	0	24	70	4	166
1996	48	42	0	0	10	7	99	89	15	310
1997	55	0	32	5	7	6	75	104	9	293
1998	58	13	52	6	12	21	48	178	10	398
1999	106	15	78	10	5	11	61	665	10	961
2000	92	121	44	34	20	7	52	325	11	706
2003*	9	0	9	5	1	2	0	92	1	119
2008*	131	45	51	43	11	29	59	58	3	430
2009*	177	212	46	11	1	17	36	390	12	902
2011*	10	5	12	2	0	5	3	32	1	70
2013*	21	2	4	5	25	3	27	221	10	318

Other investigators have used the concept of host selection to compare differences in mortality and abundance rates, with *host selection events* defined as outbreaks in which mortality rates exceed abundance rates by at least 10% (Botzler et al. 2002). In our study, Ruddy Duck, in particular, demonstrated a percentage of mortality that was consistently greater than their percentage of abundance, with average mortality rates exceeding abundance rates by 21.6% (Table 2). Although abundance of Ruddy Duck was not a significant predictor of total abundance of all waterfowl, average mortality of Ruddy Duck was a significant predictor of total mortality of all waterfowl. These results suggest that, at this site, Ruddy Duck consistently suffers a greater mortality rate from avian cholera than

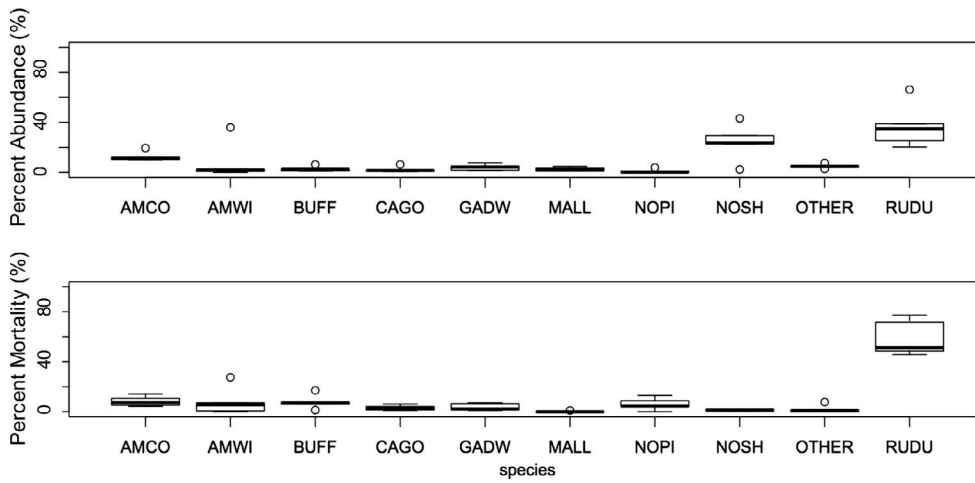

FIGURE 1. Percentage of abundance as a percentage of total abundance (above) and percentage of mortality as a percentage of total mortality (below) for waterbird species at Hayward Marsh, California, USA, for all avian cholera outbreak years (1990–2013), combined. AMCO=American Coot (*Fulica americana*); AMWI=American Wigeon (*Anas americana*); BUFF=Bufflehead (*Bucephala albeola*); CAGO=Canada Goose (*Branta canadensis*); GADW=Gadwall (*Anas strepera*); MALL=Mallard (*Anas platyrhynchos*); NOPI=Northern Pintail (*Anas acuta*); NOSH=Northern Shoveler (*Anas clypeata*); OTHER=other waterbirds; RUDU=Ruddy Duck (*Oxyura jamaicensis*).

TABLE 2. Summary of abundance and mortality measures by waterbird species at Hayward Marsh, California, USA, from 2003–13.

Species	Average abundance	Average mortality	% Abundance	% Mortality	% Difference
American Coot	345.7	23.8	11.4	8.4	−3.0
American Wigeon	381.2	48.4	8.2	8.2	0
Bufflehead	63.0	20.8	2.8	7.9	5.1
Canada Goose	37.6	9.8	2.3	3.2	0.9
Gadwall	119.3	6.0	4.1	2.0	−2.1
Mallard	60.5	11.2	2.5	3.7	1.2
Northern Shoveler	813.8	24.6	24.3	6.2	−18.1
Ruddy Duck	847.7	187	37.2	58.8	21.6

do other species, and the effect may be greater than would be expected based on their population size. Year-to-year variation among species remains large. Although Ruddy Duck consistently displayed high abundance and high mortality for all outbreak years at our study site, Northern Shoveler and America Coot also represented the greatest percentage of mortality for all species during at least one outbreak (Fig. 2).

Although comprising a considerable percentage of the total abundance, American Coot displayed a considerably lower comparative mortality rate. This finding differs from the results of earlier studies in which American Coot suffered the highest mortality rates among waterbirds (Rosen 1969; Botzler 2002). A study at the City of Arcata (California, USA) Oxidation Basins demonstrated results similar to ours (Hazlewood et al. 1978). During the avian cholera outbreak in the City of Arcata, which occurred in 1975–76, Ruddy Duck made up 62.3% of the total mortality and 33.8% of the total abundance, similar to the

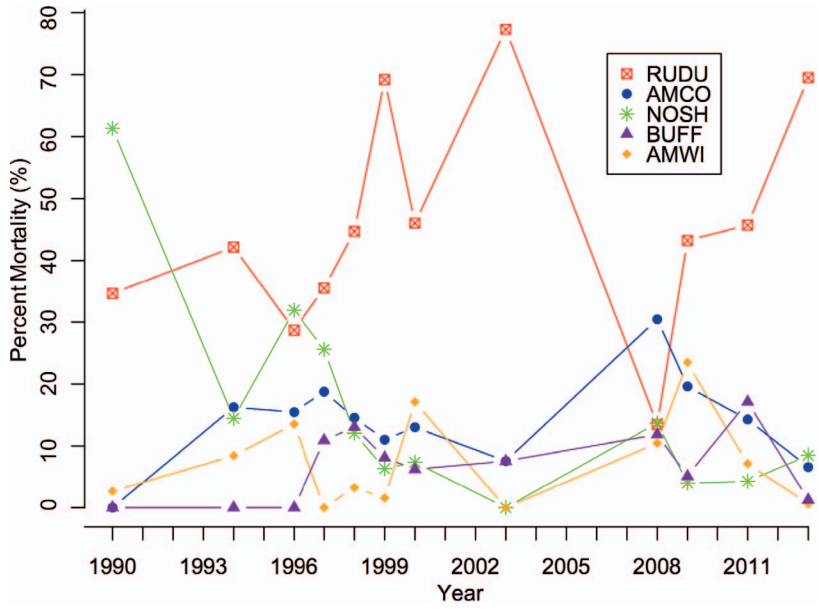

FIGURE 2. Percentage of mortality as a percentage of total mortality for each waterbird species in the 12 avian cholera outbreaks at Hayward Marsh, California, USA, during 1990–2013. See Figure 1 for explanation of species abbreviations.

percentages found at Hayward Marsh, which, for Ruddy Duck, were estimated to comprise 58.8% of the total mortality and 37.2% of the total abundance (Table 2). The comparatively high mortality rate of Ruddy Duck at these sites could be attributed to various immunologic, behavioral (e.g., migration patterns or amount of time spent foraging in water), or environmental (e.g., habitat quality) factors, which remain to be elucidated. Because *P. multocida* likely enters systems via the waterbirds themselves, interactions involving waterbird migratory patterns or community dynamics may also contribute to the species-specific differences in mortality observed at our study site.

We have demonstrated the importance of assessing species-specific dynamics in avian cholera outbreaks among sites to better inform wildlife management practices. Carcass collection remains an important strategy for limiting avian cholera spread. At Hayward Marsh, gulls (*Laridae*) are frequently observed consuming carcasses of birds that showed behavioral signs of *P. multocida* infection (A.K.W. pers. obs.). Quick removal of carcasses prevents the spread of disease by scavengers and also prevents high concentrations of bacteria from entering the environment through decomposition (Friend 1999). A recent study of marine birds in Alaska suggested that effects of global climate change may also have a role in *P. multocida* disease emergence among previously unafflicted bird species in arctic and subarctic ecosystems (Bodenstein et al. 2015). It may also be worth considering how disease dynamics change as waterbird species become more concentrated on increasingly limited wetland habitats.

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